Cunninghamia

A journal of plant ecology for eastern Australia

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Cunninghamia

A journal of plant ecology for eastern Australia

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Allan Cunningham, botanist and explorer (1791–1839)

Cover: Collage of rare plants from Wollemi National Park, clockwise from bottom left *Leionema scopulinum*, *Prostanthera hindii*, *Cynanchum elegans*, *Acacia pubescens*, *Acacia bulgaensis*, *Eucalyptus bensonii* and *Asterolasia elegans* (see Bell pages 331-371). Illustrations by L. Elkan, C Wardrop and D. Mackay.

Cunninghamia

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Rare or threatened vascular plant species of Wollemi National Park, central eastern New South Wales.

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***Abstract*:** Wollemi National Park (c. 32° 20'– 33° 30'S, 150°– 151°E), approximately 100 km north-west of Sydney, conserves over 500 000 ha of the Triassic sandstone environments of the Central Coast and Tablelands of New South Wales, and occupies approximately 25% of the Sydney Basin biogeographical region. 94 taxa of conservation significance have been recorded and Wollemi is recognised as an important reservoir of rare and uncommon plant taxa, conserving more than 20% of all listed threatened species for the Central Coast, Central Tablelands and Central Western Slopes botanical divisions. For a land area occupying only 0.05% of these divisions, Wollemi is of paramount importance in regional conservation.

Surveys within Wollemi National Park over the last decade have recorded several new populations of significant vascular plant species, including some sizeable range extensions. This paper summarises the current status of all rare or threatened taxa, describes habitat and associated species for many of these and proposes IUCN (2001) codes for all, as well as suggesting revisions to current conservation risk codes for some species.

For Wollemi National Park 37 species are currently listed as Endangered (15 species) or Vulnerable (22 species) under the New South Wales *Threatened Species Conservation Act 1995*. An additional 50 species are currently listed as nationally rare under the Briggs and Leigh (1996) classification, or have been suggested as such by various workers. Seven species are awaiting further taxonomic investigation, including *Eucalyptus* sp. 'Howes Swamp Creek' (Doherty 26), known from a single location within the park, and *Pultenaea* sp. (Olinda) from Dunns Swamp – both these species remain undescribed, but are listed as endangered species. After applying IUCN criteria to the 94 taxa, 2 are considered Critically Endangered; 11 are considered Endangered; 23 are considered Vulnerable; 3 are considered Near Threatened; 19 are considered Data Deficient; and 36 are considered of Least Concern. It is likely that additional highly restricted plant taxa await discovery in remote locations.

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Introduction

Wollemi National Park conserves over 500 000 ha of rugged, dissected sandstone country within the Greater Sydney area of New South Wales, covering approximately 25% of the Sydney Basin biogeographical region. Together with other nearby reserves, Wollemi forms part of the large, mostly unmodified expanse of sandstone landscapes of the Greater Blue Mountains World Heritage Area which collectively conserve an impressive diversity of flora and fauna habitats. After Kosciusko National Park, Wollemi National Park is currently the second largest conservation reserve within New South Wales, and sizable sections have been declared as Wilderness under the New South Wales *Wilderness Act 1987* (Helman, Jones, Pigram & Smith 1976; Gold & Princas 1978; National Parks & Wildlife Service 1996b).

The diversity of habitats in Wollemi is reflected in the total number of species recorded (c. 1600 species) and in the large number of rare or threatened vascular plant species recorded. For an idea of the richness of the non-vascular flora see Downing et al (2007). Systematic vegetation survey undertaken in Wollemi over the past decade has revealed new records of rare, threatened or other significant plant taxa.

While there are a number of treatments of rare and threatened plant species within the Sydney Basin (eg: Briggs & Leigh 1996; James et al. 1999; Miller 2002; Fairley 2004), none have focused solely on Wollemi National Park. This paper aims to consolidate all records of significant taxa from the park, as well as to highlight the important role that Wollemi plays in the preservation of biodiversity in the Greater Sydney region. Information on associated species and habitat are provided where available, and in some cases population sizes are discussed.

Study Area

Wollemi National Park (c. 32° 20'– 33° 30'S, 150°– 151°E), is approximately 100 km north-west of Sydney (Figure 1), and forms part of an extensive system of relatively unmodified and interconnected sandstone landscapes, much of which is part of the Greater Blue Mountains World Heritage Area.

The Park is bounded in the north by the Hunter Valley floor, Goulburn River National Park, and the towns of Bulga, Jerrys Plains, Denman and Bylong; in the south by the Bells Line of Road, Blue Mountains National Park, and Bell, Bilpin and Kurrajong Heights; in the east by the Putty Road and Putty State Forest; and in the west by the cleared grazing lands of the Central Western Slopes, and the towns of Glen Alice, Kandos and Rylstone. Parts of the local government areas of Rylstone, Muswellbrook, Singleton, Hawkesbury, and Greater Lithgow occur within the park.

Environmental setting

Wollemi National Park falls within the Sydney Basin Biogeographic Region (of Thackway & Cresswell 1995), a region of of dissected plateaus of Mesozoic sandstones and shales, supporting forests, woodlands and heaths on skeletal sandy and podzolic soils. Thackway and Cresswell (1995) indicated that over 10% of the land area (the maximum category in that publication) within this region is reserved primarily for nature conservation, although the true figure is much higher than this. Indeed, there are currently over seventy conservation reserves within this region. Wollemi National Park, at just over half a million hectares, represents the largest of these reserves.

Wollemi is regionally situated between Goulburn River, Gardens of Stone, Blue Mountains, and Yengo National Parks, Pantoneys Crown Nature Reserve, and Parr State Conservation Area, and forms an integral link in the chain of protected natural lands surrounding the Sydney metropolitan area (National Parks & Wildlife Service 1996a). Important links through Wollemi connect the Sydney, Hunter, Tablelands, and Central Western Slopes landscapes. The large size of Wollemi National Park is reflected in the range of state botanical subdivisions (Anderson 1961) occurring. In Wollemi, four subdivisions, the North Coast, Central Coast, Central Western Slopes and Central Tablelands occur.

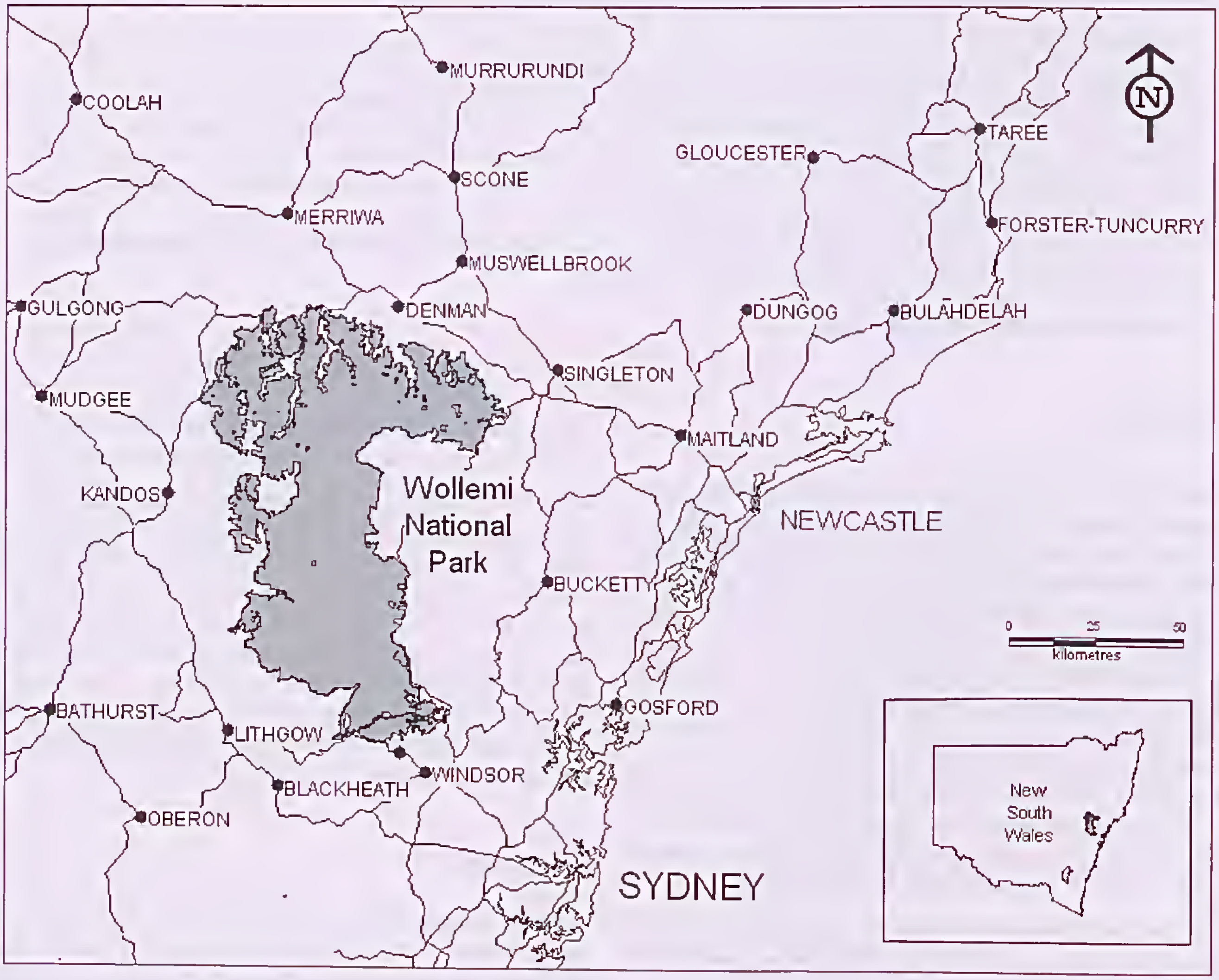

Fig. 1. Location of Wollemi National Park in central eastern New South Wales.

The interplay of these four botanical subdivisions with their differing climatic conditions provides floristically distinct areas, where elements of coastal, tablelands and western floras may be found in close proximity. In no other location in New South Wales are the influences of all three elements represented within one conservation reserve.

Climate

Extending from the drier western portions of the Hunter Valley, to the wetter and cooler tablelands of the Blue Mountains, Wollemi experiences a wide range of climatic variation. Principal influences on weather patterns are elevation, and proximity to coastal and continental influences. The weather patterns in the Hunter Valley, which encompasses the northern sections of the reserve are summarised Bridgeman (1984).

In elevation terms, Wollemi National Park can be bisected along a north-south axis, with the eastern half ranging between 100 and 500m ASL, and the western half between 500 and 1000m ASL. The eastern half is influenced more by coastal air masses moving along the New South Wales coastline, while the western sections are influenced by westerly moving continental air masses. More elevated areas, such as the basalt-capped mountains on the western side, are also subject to local orographic climatic affects.

Annual average monthly rainfall figures for Wollemi National Park are highly variable and directly reflect geographical location and elevation. The northern portions are typically very dry, ranging from maxima of 80–90 mm/month during summer at Kerrabee, Bylong, and Bulga, to as low as 25 mm/month during cooler periods (NPWS, pers. comm.). Annual figures for these three centres are approximately 650, 670 and 680 mm/year respectively, with 636 mm/year also reported for Jerrys Plains (Bureau of Meteorology 2008).

The western escarpment is also dry, with annual figures of 650, 700 and 625 mm/year for Olinda, Kandos, and Glen Alice, showing similar monthly maxima to the northern escarpment, but lows of 35–40 mm/month during winter. At Nullo Mountain, on the Central Tablelands near the central-west of the park, maximum falls of 170 mm in January contrast markedly to the <5 mm in April and August, although records have only been maintained at this station for a five year period. Annual figures here are reported as 730 mm/year, although they are likely to be considerably higher during wetter years (NPWS pers. comm.).

Along the eastern side of the park, higher rainfall is received from coastal air masses, with Howes Valley ranging from approximately 30–110 mm/month (July– January), and Colo Heights 40–130 mm/month (July–February). These stations have average annual figures of 805 and 1032 mm/year respectively (NPWS pers. comm.).

To the south and south-east, high rainfall is also received in the northern Blue Mountains. Bilpin, towards the south-east, receives around 1300 mm annually, with maxima of 150–170 mm in January–February and minima of 68–76 mm in June–August. At nearby Kurrajong Heights, annual figures of 1253 mm are reported, with similar monthly ranges (Bureau of Meteorology 1998). Further west, Mt Wilson receives 1228 mm/year, with around 70 mm/month in August–September, to 153 mm/month in February, while Newnes State Forest in the south-west of the park receives 1073 mm/year (Bureau of Meteorology 2008). To the north of the Newnes Plateau, rainshadow effects are strongly evident, with lower rainfalls reported for the Capertee and Wolgan Valleys, and figures as low as 621 mm/year noted for Glen Alice, and 634 mm/year for Glen Davis (Bureau of Meteorology 1998). Similar figures generally continue north along the western escarpment of the park.

Seasonality of rainfall is generally consistent across most of the area, with the highest falls occurring between January and March, and the lowest in the July–August period (Bureau of Meteorology 2008). In some western districts, such as Olinda, seasonality is less pronounced but still apparent.

Average maximum and minimum temperatures also vary widely throughout the park. In the north at Jerrys Plains, average temperatures range from 3.7°–31.8° C (Bureau of Meteorology 1998), while Nullo Mountain in the west shows a range of 2.3°–23.7° C (NPWS pers. comm.). Ranges of 2°–28°C are provided by Ryan, Fisher and Schaeper (1996) for the St Albans 1:100 000 map sheet, which includes the south-eastern section of the park. In the south-west, the elevated Newnes Plateau and associated Central Tablelands exerts a strong influence on temperatures, with average maximum temperatures for January of 25.4°C for Lithgow, 23.2°C at Newnes State Forest, and 27°C in the Capertee Valley. Average minimum temperatures for July are 0.6°C at Lithgow and -0.8°C in Newnes State Forest. Glen Davis, on the western edge of the park, ranges from a minimum of 2.0°C in July, to a maximum of 30.3°C in January (Bureau of Meteorology 2008). The extreme south-western sections of the park (Newnes Plateau) may receive light snow falls for elevations above 1000m ASL (Bureau of Meteorology 2008).

Geology and soils

Wollemi National Park lies on the north-western edge of the Sydney Basin geological unit that stretches from Batemans Bay in the south, to the Hunter Valley in the north. The Sydney Basin Geological unit approximates the Sydney Basin Biogeographical Region of Thackway and Cresswell (1995). Wollemi National Park lies within the Blue Mountains Plateau structural unit of the Sydney Basin (Bembrick *et al.* 1973). This plateau rises from an elevation of 300 m ASL in the east, to around 1100 m ASL in the west; dramatic gradients in rainfall, temperature, relative humidity, and wind speed are associated with this rise. This area is commonly referred to as the Blue Mountains Dissected Sandstone Plateau, and is characterised by dramatic valleys and clifflines. This part of the Sydney Basin also exhibits a tilting to the north-west, giving rise to dramatic cliff lines along the western escarpment of the park. The major geological types occuring in Wollemi National Park (listed from geologically oldest) are Permian sediments and coal measures, Triassic Narrabeen and Hawkesbury sandstones, and Wianamatta Shale, Tertiary basalt and Quaternary alluvium.

Permian sediments

The Illawarra and Singleton Coal Measures underlie the Triassic Sandstones, and outcrop in the western and northern fringes of the park. These outcrops occur only in gully situations, and typically produce steep talus slopes surmounted by sheer cliffs of the Triassic Sandstones. The Permian Sediments comprise a complex of shale, sandstone, conglomerate, tuff, chert, coal and torbanite seams (Brunker & Rose 1967), and are highly erodible. The coal seams in the Hunter Valley have been mined for high quality coal for many years.

Triassic Narrabeen Sandstones

The Triassic Narrabeen sediments occupy the majority of the park, and consist of multi-coloured chert sandstone, quartzose sandstone, shales and claystones (Brunker & Rose 1967). The thickness and extent of shale and claystone layers are highly variable, and in places give rise to flat plateaus and saddles. The shale bands allow undercutting erosion to produce incised valleys typical of the Blue Mountains Plateau.

Triassic Hawkesbury Sandstone

Triassic Hawkesbury Sandstone generally occurs in the south-eastern portions of the park around Colo, but extends a small way into the eastern edge of the park along the Lapstone Monocline (Branagan 1969). This sequence is primarily composed of quartz sandstone layers, with minor shale (Brunker & Rose 1967). Bembrick, Herbert and Clark (1991) indicate that the Hawkesbury Sandstone contains detrital grains averaging 68% quartz, 2% rock fragments and clay pellets, 1% feldspar and mica, 20% clay, 6% secondary quartz, and more than 4% siderite, and that the sandstone is dominantly medium to course-grained in texture, but varies from fine to very coarse grained. Mudstone facies, ranging from 0.5–3m in thickness also occur between sandstone beds (Bembrick, Herbert & Clark 1991).

Triassic Wianamatta Shale

Wianamatta Shale is restricted to a few isolated locations in the south-east of the park, such as along the Culoul Range, where it forms remnant caps over the Triassic Hawkesbury Sandstone, although it is more widespread on the Cumberland Plain in western Sydney. Only remnants of the Ashfield Shales (Bembrick, Herbert & Clark 1991) (hereafter referred to as Wianamatta Shale) occur within Wollemi.

Tertiary basalt

Small areas of Tertiary age basalt material occur in the park, particularly in the north-west (Brunker & Rose 1967). Such material may take the form of basalt caps, from large-scale volcanic surface flows (as on Mt Monundilla, Mt Coricudgy), to much smaller diatremes or dykes.

For the Hunter Valley area, Galloway (1967) indicates that a massive outpouring of basalt occurred during the Lower Tertiary period, followed by some minor volcanicity during the Pliocene or early Pleistocene. The many basalt caps currently present in the north-western sections of Wollemi represent remnants of this initial basalt flow. Galloway (1967) cites thicknesses of these flows of up to 150m for Mt Coricudgy, and possibly 230m on Kerry Mountain.

Further south, occurrences of basalt and related material are less common, and more typically consist of diatremes and dykes. Brownlow et al. (1991) describe three diatremes north of Kurrajong (the Bull Ridge, Tennyson and Diamond Hill diatremes), near the Wollemi National Park boundary, stating their composition to be volcanic breccia and alkali-olivine basalt. In contrast to diatremes, no volcanic dykes are apparent west of the Lapstone Monocline, although this may be a reflection of the ruggedness of the topography and the lack of detailed survey (Brownlow et al. 1991).

Quaternary Alluvium

Small areas of Quaternary Alluvium occur commonly along river valleys across most of Wollemi. Such alluvial material typically consists of varying compositions of gravel, sand, silt and clay (Brunker & Rose 1967). Larger instances of alluvium also occur in the Mellong Swamps and Garland Valley areas, where deep sands have accumulated over a clay sub-soil layer, producing a distinctly different environment (Henry 1987; Riley & Henry 1987).

Methods

As part of the reserve management program for Wollemi National Park, flora survey and vegetation mapping was undertaken for the NSW National Parks and Wildlife Service (NPWS) in 1997–98 (Bell 1998) (a revision of that work is currently underway with the NSW Department of Environment and Climate Change). The 1997–98 floristic field surveys of Wollemi National Park (covering over 200 sites), included a large number of new records of rare or threatened plant species (incorporated into the survey report of Bell 1998). Subsequent forays into the park for various survey and mapping projects have resulted in additional records which have now been amalgamated and incorporated with databases (eg: DECC Atlas) and the taxonomic literature.

All rare or threatened taxa recorded within Wollemi National Park, i.e. listed under the Commonwealth *Environment Protection and Biodiversity Conservation* (EPBC) Act (1999) or NSW *Threatened Species Conservation* (TSC) Act

Table 1. Conservation Risk Codes of Briggs and Leigh (1996)

Code	
Distribution	
1	known from one collection only.
2	geographical range in Australia less than 100km.
3	geographical range in Australia greater than 100km.
Conservation status	
X	**Presumed Extinct**: not collected or otherwise verified over the past 50 years despite thorough searching in all known or likely habitats, or of which all known wild populations have e been destroyed more recently.
E	**Endangered**: in serious risk of disappearing from the wild within 10–20 years if present land use and other threats continue to operate. This category includes taxa with populations possibly too small (usually less than 100 individuals) to ensure survival even if present in proclaimed reserves.
V	**Vulnerable**: not presently Endangered, but at risk over a longer period (20–50 years) of disappearing from the wild through continued depletion, or which occurs on land whose future use is likely to change and threaten its survival.
R	**Rare**: rare in Australia (and hence usually in the world) but which currently does not have any identifiable threat. Such species may be represented by a relatively large population in a very restricted area or by smaller populations spread over a wide range or some intermediate combination of distribution pattern.
K	**Poorly Known**: suspected, but not definitely known, to belong to one of the above categories. At present, accurate field distribution information is inadequate.
C	**Reserved:** has at least one population within a national park, other proclaimed conservation reserve or in an area otherwise dedicated for the protection of flora. The taxon may or may not be considered adequately conserved within the reserve(s), as reflected by the conservation status assigned to it. Where applicable, the 'C' symbol immediately follows the conservation status symbol in the written code, eg 2RC.
Reserved populations	
a	1000 plants or more are known to occur within a conservation reserve(s).
i	less than 1000 plants are known to occur within a conservation reserve(s).
-	reserved population size is not accurately known.
t	total known population reserved
+	overseas occurrence (included if the taxon has a natural occurrence overseas).

Table 2. IUCN Red List Categories (IUCN 2001).

Extinct	EX	there is no reasonable doubt that the last individual has died. A taxon is presumed extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.
Extinct in the Wild	EW	known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside the past range. A taxon is presumed Extinct in the Wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.
Critically Endangered	CR	the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered, and it is therefore considered to be facing an extremely high risk of extinction in the wild.
Endangered	EN	the best available evidence indicates that it meets any of the criteria A to E for Endangered, and it is therefore considered to be facing a very high risk of extinction in the wild.
Vulnerable	VU	the best available evidence indicates that it meets any of the criteria A to E for Vulnerable, and it is therefore considered to be facing a high risk of extinction in the wild.
Near Threatened	NT	it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.
Least Concern	LC	it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.
Data Deficient	DD	there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution are lacking. Data Deficient is therefore not a category of threat. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases great care should be exercised in choosing between DD and a threatened status. If the range of a taxon is suspected to be relatively circumscribed, and a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.
Not Evaluated	NE	has not yet been evaluated against the criteria.

(1995), or as a ROTAP species (Briggs & Leigh 1996) have been identified. For each species, information on location within Wollemi National Park, habitat, potential threats and conservation status were tabulated. Where possible, habitat information has been drawn directly from field survey information and includes commonly associated species. The information has been discussed with relevant botanical experts, particularly those at the National Herbarium of New South Wales in Sydney. Extensive herbarium searches or examination of archival material has not been undertaken. Table 1 summarises the conservation risk codes of Briggs and Leigh (1996).

The conservation assessment scheme developed by the International Union for Conservation of Nature (IUCN) Is now being widely accepted and increasingly used in NSW particularly for assessment under the *TSC Act*. With the exception of *Wollemia nobilis* (listed as CR D on the current IUCN Red List) there are no published IUCN codings for any of the Wollemi National Park species listed here. Codings developed under IUCN rules are given in Table 2. Coding for species have been determined by examining each against the criteria of IUCN (2001), utilising the available information on known distribution and populations throughout their entire geographical range, habitat and potential threats within that habitat, plant habit and known reproductive traits, and known population sizes.

Results

For Wollemi National Park, 94 taxa are currently regarded as rare or threatened. These are listed in Table 3, with their current conservation status, under the Commonwealth *Environment Protection & Biodiversity Conservation* (EPBC) Act, and the NSW *Threatened Species Conservation* (TSC) Act, which provide legislative protection, and as the conservation risk code scheme presented in Briggs and Leigh (1996).

Fifteen species are currently listed as Endangered and 22 as Vulnerable under the NSW TSC Act. An additional 50 species are currently listed as nationally rare under the Briggs and Leigh (1996) ROTAP classification (Table 1), or have been suggested as such by various workers. Seven species are awaiting further taxonomic investigation, including *Eucalyptus* sp. 'Howes Swamp Creek' (Doherty 26), known from a single location within the park, and *Pultenaea* sp. (Olinda) from Dunns Swamp – both these species remain undescribed, but are listed as endangered species.

Proposed IUCN codings are provided in Table 3. After applying IUCN criteria to the 94 taxa, 2 are considered Critically Endangered; 11 are considered Endangered; 23 are considered Vulnerable; 3 are considered Near Threatened; 19 are considered Data Deficient; and 36 are considered of Least Concern. For some species currently listed as Endangered (eg: *Apatophyllum constablei*) or Vulnerable (*Eucalyptus cannonii*) on the EPBC Act, recently acquired survey data has suggested that these are now of relatively little concern with respect to conservation priorities.

Rare or threatened plant species of Wollemi National Park

1. *Acacia asparagoides* A. Cunn. (Fabaceae: Mimosoideae)

Distribution within Wollemi– a single DECC Atlas record from 1965 for the Glen Davis area, in the south-west of the park.

Habitat – Tame (1992) indicates that this species occurs on sandstone plateaus in heath and open forest in the upper and northern Blue Mountains. Douglas and Bell (in prep.) have recorded this species within open forest dominated by *Eucalyptus sieberi* and *Eucalyptus piperita* in the higher Blue Mountains.

Threats – no threats identified.

Conservation Status – populations also present within Blue Mountains National Park (pers. obs.). Benson and Keith (1990) report populations in the Blackheath and Newnes Plateau areas, which may be contiguous with the Glen Davis record.

EPBC Act **not listed**; *TSC Act* **not listed**; *IUCN (2001)* **LC (proposed)**; *ROTAP*: **2R**

2. *Acacia bulgaensis* Tindale & Stuart J. Davies (Fabaceae: Mimosoideae) Bulga Wattle

Distribution within Wollemi – occurs in the north-east of Wollemi, mainly where it adjoins Yengo NP, around Bulga and Milbrodale, and south along the Putty Road.

Habitat – varies from an exposed low open woodland or forest where *Acacia bulgaensis* clearly dominates the vegetation, to being occasional in better structured open forest. Maryott-Brown and Wilks (1993) describe the habitat as occupying crests and upper slopes of Narrabeen Sandstone ridges, where it is commonly found in dry sclerophyll woodland with *Eucalyptus punctata* and *Eucalyptus fibrosa*, over an understorey of *Backhousia myrtifolia* and *Choretrum* sp. A, and various herb and grass species.

Threats – frequent fire events may exhaust seed banks rendering local extinction.

Conservation Status – also known from adjoining Yengo NP (Tindale, Kodela & Davies 1992; Maryott-Brown & Wilks 1993). A revised conservation risk code of 2RCa has been suggested by Bell (2001), on the basis that well over 1000 plants are known from conservation reserves.

EPBC Act: **not listed**; *TSC Act*: **not listed**; *IUCN (2001)*: **LC (proposed)**; *ROTAP*: **2RC–; 2RCa (Bell 2001)**

3. *Acacia bynoeana* Benth. (Fabaceae: Mimosoideae) Tiny Wattle

Distribution within Wollemi – single record for the Morans Rocks area in the south-east, where three plants were observed in 1999 (DECC Atlas). Given the tendency for further populations and greater population sizes to be uncovered with targeted survey, there is some potential that greater numbers are present within the park. New populations have recently been discovered in the western parts of the adjacent Yengo NP near Colo Heights (pers. obs.).

Habitat – Fairley (2004) describes a habitat of sandy clay soils often containing ironstone gravels, in open forest and shrubland, usually on ridge tops. Recently recorded populations in the adjacent Yengo NP occur in scrub dominated by *Angophora hispida*, *Petrophile pulchella*, *Leptospermum trinervium*, *Leucopogon attenuatus*, *Banksia serrata*, *Grevillea buxifolia*, *Hakea laevipes* subsp. *laevipes* and *Pimelea linifolia* subsp. *linifolia*, over a ground layer of *Ptilothrix deusta*, *Lomandra glauca*, *Cyathochaeta diandra*, *Entolasia stricta*, *Phyllanthus hirtellus*, *Schoenus imberbis* and *Xanthorrhoea resinifera*.

Threats – inadvertent road maintenance and widening.

Table 3. Rare or threatened plant species known from Wollemi National Park. IUCN codes are as listed in the IUCN Red List Database 2006. ROTAP codes shown within "[ ]" represent codes recommended by various authors, and are not shown as such within Briggs and Leigh (1996). * = recovery plan prepared.
IUCN Codes: Critically Endangered = CR; Endangered = EN; Vulnerable = VU; Near Threatened = NT; Least Concern = LC; Data Deficient = DD (IUCN 2001).

Species number in text	Species	EPBC Act	NSW TSC Act	IUCN (2001)	Briggs & Leigh (1996)	
				Proposed	Current	Proposed
1	*Acacia asparagoides*			LC	2R	-
2	*Acacia bulgaensis*			LC	2RC-	-
3	*Acacia bynoeana*	V	E	NT	3VC-	-
4	*Acacia flocktoniae*	V	V	LC	2VC-	-
5	*Acacia fulva*			LC	2RC-	2RCa
6	*Acacia gordonii*	E	E	NT	2K	-
7	*Acacia matthewii*			LC	3RC-	-
8	*Acacia pubescens*	V	V	VU A2be	3VCa	-
9	*Acacia subtilinervis*			LC	3RCa	-
10	*Almaleea incurvata*			LC	2RC-t	2RC-
11	*Apatophyllum constablei*	E		LC	2EC-	2RCa
12	*Asterolasia elegans*	E	E	EN C2b	2Eea	-
13	*Atkinsonia ligustrina*			LC	2RCa	-
14	*Baeckea kandos*	E	E	EN D1	2RC-t	-
15	*Banksia penicillata*			LC	3RC-	-
16	*Blechnum gregsonii*			DD	2RCa	-
17	*Boronia barkeriana* subsp. *barkeriana*			DD	-	[2RC-]
18	*Boronia floribunda*			LC	-	[2RC-]
19	*Boronia fraseri*			LC	2RCa	-
20	*Boronia rubiginosa*			LC	2RCa	-
21	*Brasenia schreberi*			DD	3RC-+	-
22	*Callistemon shiressii*			LC	3RC-	-
23	*Cynanchum elegans*	E	E	VU D2	3ECi	-
24	*Cyphanthera scabrella*			DD	2RC-	-
25	*Darwinia peduncularis*		V	LC	3RCi	-
26	*Diuris* sp. aff. *punctata* (Colo River)			DD	-	2KC
27	*Epacris coriacea*			VU D2	3RC-	-
28	*Epacris muelleri*			VU D2	3RC-	-
29	*Eucalyptus aenea*			VU D2	2RC	[2RC-}
30	*Eucalyptus bensonii*			VU D2	2RC-t	-
31	*Eucalyptus burgessiana*			VU D2	2RCa	-
32	*Eucalyptus cannonii*	V	V	LC	2VCi	[2RCa]
33	*Eucalyptus corticosa*		V	VU D2	-	2VC-
34	*Eucalyptus fergusonii* subsp. *dorsiventralis*			LC	2RC-	-
35	*Eucalyptus gregsoniana*			DD	3RCa	-
36	*Eucalyptus hypostomatica*			LC	3RC-	-
37	*Eucalyptus prominula*			LC	2KC-	-
38	*Eucalyptus* sp. aff. *eugenioides* (Bees Nest Ridge)			DD	-	3KC
39	*Eucalyptus* sp. 'Howes Swamp Creek' (Doherty 26)	E	E	CR D1	2ECi	-
40	*Gonocarpus longifolius*			LC	3RC-	[3RCa]
41	*Grevillea evansiana*	V	V	LC	2VC-	2VCa
42	*Grevillea johnsonii*			LC	-	2RCi [2RCa]
43	*Grevillea montana*			LC	2KC-	[2RCa]
44	*Grevillea obtusiflora* subsp. *obtusiflora*	E	E	VU D1+2	2E	-
45	*Gyrostemon thesioides*		E	EN D1	-	2EC
46	*Haloragodendron gibsonii*	E	E	EN D1	2Reat	-

Species number in text	Species	EPBC Act	NSW TSC Act	IUCN (2001)	Briggs & Leigh (1996)	
				Proposed	Current	Proposed
47	*Homoranthus cernuus*			LC	2RCa	-
48	*Isotropis foliosa*			VU D2	3KC-	-
49	*Kennedia retrorsa*	V	V	DD	2VCa	2VCi
50	*Keraudrenia corollata* var. *denticulata*			DD	3RC-	-
51	*Leionema lamprophyllum* subsp. *orbiculare*			DD	-	[2R-]
52	*Leionema scopulinum*			VU D2	-	[2RCit]
53	*Leionema sympetalum*	V	V	NT	2VC-	-
54	*Leionema* sp. 'Colo River' (Weston 2423)			DD	-	[2VC-]
55	*Leptospermum spectabile*			VU D1+2	2RC-	2RCt
56	*Leucochrysum graminifolium*			LC	2R	2RC-
57	*Lissanthe sapida*			LC	3RCa	-
58	*Lomandra fluviatilis*			LC	3RCa	-
59	*Macrozamia elegans*			EN A2ad	-	[2VC-]
60	*Melaleuca deanei*	V	V	VU C2(ai)	3RC-	-
61	*Melaleuca groveana*		V	VU C2(ai); D2	3RC-	-
62	*Olearia cordata*	V	V	VU B1; C2b	2VCi	-
63	*Olearia quercifolia*			LC	3RC-	-
64	*Ozothamnus tesselatus*	V	V	VU B1	2VC-	-
65	*Pentachondra dehiscens*			VU D2	-	[3RC]
66	*Persoonia hirsuta* var. *evoluta*	E	E	EN B1	3Kci	-
67	*Persoonia marginata*	V	V	EN B1	2V	-
68	*Philotheca obovalis*			LC	3RCa	-
69	*Pimelea curviflora* var. *curviflora*	V	V	EN B1	-	2VC-
70	*Platysace clelandii*			LC	2RCa	-
71	*Pomaderris bodalla*		V	VU D2	-	[2R]
72	*Pomaderris brunnea*	V	V	DD	2VC-	-
73	*Pomaderris pauciflora*			DD	3RC-	-
74	*Pomaderris precaria*			VU D1	-	[2VC-] [2EC-]
75	*Pomaderris sericea*	V	E	EN D1	3VCi	-
76	*Pomaderris* sp. aff. *nitidula* (Glen Gallic)			DD	-	2KC
77	*Prostanthera cryptandroides*	V	V	VU D2	2RC-t	[2VC-]
78	*Prostanthera discolor*	V	V	VU D2	2VC-	-
79	*Prostanthera hindii*			LC	2KC-	-
80	*Prostanthera* sp. A (Rylstone)			DD	-	2KC-
81	*Prostanthera* sp. aff. *rotundifolia*. (Mt Iris)			DD	-	2KC-
82	*Prostanthera stricta*	V	V	VU D2	2V	-
83	*Pseudanthus divaricatissimus*			LC	3RCa	-
84	*Pultenaea glabra*	V	V	DD	3VCa	-
85	*Pultenaea* sp. (Olinda)		E	EN B1	-	2EC-
86	*Rulingia hermanniifolia*			LC	3RCa	-
87	*Rulingia* sp. aff. *dasyphylla* (Goulburn River Valley)			DD	-	2KC
88	*Rupicola ciliata*			LC	2RC-t	-
89	*Rupicola decumbens*			LC	2RC-	-
90	*Swainsona recta*	E	E	DD	3ECi	-
91	*Tetratheca glandulosa*	V	V	LC	2VC-	-
92	*Velleia perfoliata*	V	V	VU B2ac(iv); D1	2VC-	-
93	*Wollemia nobilis*	E	E	[CR D]	2Ecit	-
94	*Zieria involucrata*	V	E	EN A1a; B1	2VCa	-

Conservation Status – *Acacia bynocana* extends from the Sydney area north to Cessnock (Kodela & Harden 2002: pers obs.). Briggs and Leigh (1996) noted conserved populations present in Blue Mountains and Royal NPs. Several other reserved populations are now known in Yengo, Marramarra and Popran NPs, Lake Macquarie State Conservation Area, and Castlereagh, Dharawal and Agnes Banks Nature Reserves (NSW Scientific Committee 1999; James 1997). Large populations are also present in the Cessnock area of the Hunter Valley, but none of these are currently present in conservation reserves (Bell & Driscoll 2007). Driscoll (2006) summarises all available information on this species.

EPBC Act: **Endangered**; *TSC Act*: **Endangered**; *IUCN (2001)*: **NT (proposed)**; *ROTAP*: **3VC-**

4. *Acacia flocktoniae* Maiden (Fabaceae: Mimosoideae)

Distribution within Wollemi – historical record for the Coxs Gap area in the north of Wollemi from 1968, but possibly in error since this locality occurs well north of its accepted range (Mt Wilson to Picton). No indication of this species was noted during survey in this area (Bell 1998), nor of the adjacent Goulburn River NP (Hill 1999). A collection was made from the sandstone hills around Mellong Swamps in the east of the park (Doherty 1985). New collections are required to confirm its presence within the park.

Habitat – no information available.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) stated that this species is conserved only within Blue Mountains NP. Fisher et al. (1995) also record it for Yerranderie, most likely within Yerranderie State Conservation Area and the Blue Mountains World Heritage Area.

EPBC Act: **Vulnerable**; *TSC Act*: **Vulnerable**; *IUCN (2001)*: **LC (proposed)**; *ROTAP*: **2VC-**

5. *Acacia fulva* Tindale (Fabaceae: Mimosoideae) Soft Wattle

Distribution within Wollemi – known from "California" and "Winter's Run" in the north-east of the park, in both cases associated with isolated basalt soils.

Habitat – At both locations, *Acacia fulva* clearly dominates the area, and is regenerating profusely following the cessation of grazing practices. *Eucalyptus moluccana*, *E. tereticornis* and *E. punctata* dominate the canopy on basalt soils, over a grassy understorey with scattered shrubs. In nearby areas on Narrabeen Sandstone soils, dense stands of *Acacia fulva* are also present in open forest of *Eucalyptus sparsifolia* and *E. punctata*, over a dense understorey of *Podolobium ilicifolium*, *Acacia prominens*, *Acacia filicifolia*, *Indigofera australis* and *Commersonia fraseri*. Smaller populations can be found up to several kilometres from the basalt soils, within the wider *Eucalyptus sparsifolia* – *E. punctata* open forest that dominates this part of the park. Based on observations made in mid-2005, many thousands of *Acacia fulva* individuals are present within Wollemi NP, with considerable germination evident following wildfires in the last decade. In some of the denser areas of regrowth, between 10 and 15 stems per square metre are present across an area of at least 1 ha. Maryott-Brown and Wilks (1993) indicated that in the adjacent Yengo NP, *Acacia fulva* also occurs on basalt-derived soils in open forest dominated by *Eucalyptus tereticornis* and *E. moluccana*. They also documented its presence within a sheltered forest of *Angophora floribunda* and *Allocasuarina torulosa*, with *Acacia fulva* and *Backhousia myrtifolia* dominating the shrub layer, and *Adiantum aethiopicum* and *Oplismenis imbecillis* in the groundlayer.

Threats – frequent fire events may exhaust seed banks.

Conservation Status – Briggs and Leigh (1996) list this species as occurring in unknown population sizes within Wollemi NP, while Maryott-Brown and Wilks (1993) detail the species' occurrence in Yengo NP. In view of the large populations evident within Wollemi, together with the likelihood of high numbers of seed present within

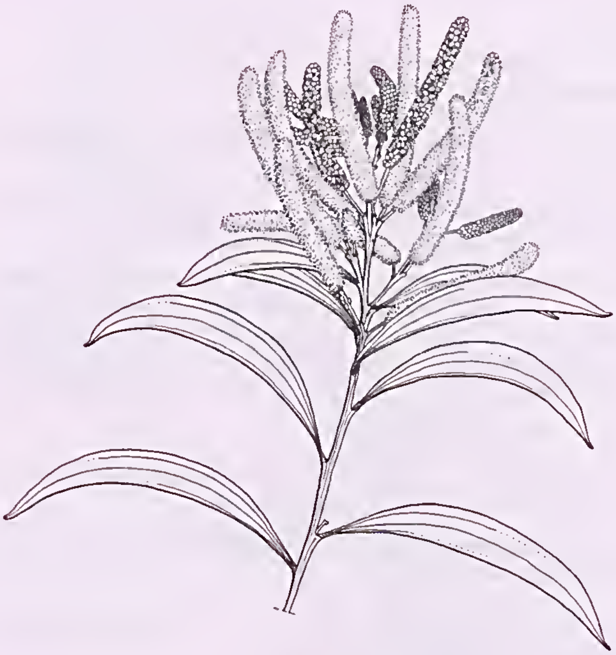

Fig. 2. *Acacia bulgaensis* (illustration by Don Fortescue)

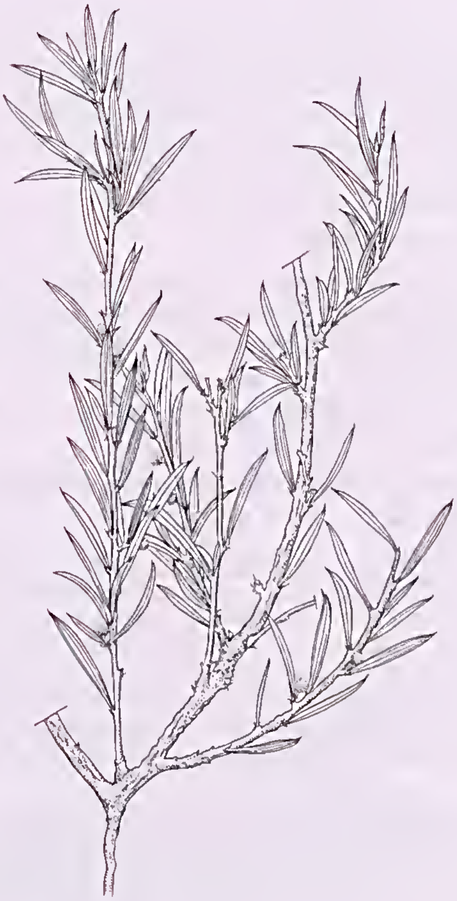

Fig. 3. *Acacia bynocana* (illustration by C. Wardrop 2001)

the soil seedbank, a revision to the conservation risk code to 2RCa is suggested.

EPBC Act: **not listed**; *TSC Act*: **not listed**; *IUCN (2001)*: **LC (proposed)**; *ROTAP*: **2RC-; 2RCa (proposed)**

6. *Acacia gordonii* (Tind.) Pedley (Fabaceae: Mimosoideae)

Distribution within Wollemi – occurs only above Wheeny Creek near Bilpin in the extreme south of the park; other populations occur within the nearby Blue Mountains NP (1985 record, DECC Atlas).

Habitat – Tame (1992) describes habitat for this species as dry heath in eucalypt woodland, usually on shallow sandy soil among sandstone outcrops, while James *et al.* (1999) indicate rocky platforms on ridgetops and rocky spurs of Hawkesbury Sandstone, often with a clay influence. Fairley (2004) also includes lateritic influences near rocky outcrops.

Threats – no threats identified.

Conservation Status – James (1997) notes that this species is not protected in any other conservation reserve.

EPBC Act: **Endangered**; *TSC Act*: **Endangered**; *IUCN (2001)*: **NT (proposed)**; *ROTAP*: **2K**

7. *Acacia matthewii* Tindale & Stuart J. Davies (Fabaceae: Mimosoideae) Matthew's Wattle

Distribution within Wollemi – occurs in the west of the park, around Rylstone and Kandos, further south near Capertee and the Newnes Plateau, and in Howes Valley area to the east (Tindale, Kodela & Davies 1992).

Habitat – Tindale, Kodela & Davies (1992) indicate that this species occurs in sandy soil on sandstone ridges or steep rocky hillsides, especially on the northern faces at the head of creeks, at the margins of wet sclerophyll forest, and also on Narrabeen Sandstone shale lenses. Tame (1992) more broadly states "eucalypt forests and woodlands in hilly country on well drained soils", and Fairley (2004) includes steep rocky hillsides, especially on north-facing heads of creeks, at margins of wet sclerophyll forest, or in shale deposits.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list this species as occurring in Wollemi, Yengo and Dharug NPs. Washington (2001a) also notes a record of this species for the Wolgan Pinnacle area of Gardens of Stone NP.

EPBC Act: **not listed**; *TSC Act*: **not listed**; *IUCN (2001)*: **LC (proposed)**; *ROTAP*: **3RC-**

8. *Acacia pubescens* (Vent.) R.Br. (Fabaceae: Mimosoideae) Downy Wattle

Distribution within Wollemi – recorded in 1993 in the Mountain Lagoon area in the south-east; also in the Mt Popong area in the north-east (DECC Atlas). A 1980s population estimate of over 2000 plants at Mountain Lagoon has not been recently substantiated; however numbers are likely to fluctuate with fire history. The small number of reported records for Wollemi suggest that the species is inadequately conserved in this park, however as with many wattles it is likely that population numbers will fluctuate widely following disturbances such as fire.

Habitat – Maryott-Brown and Wilks (1993) indicate that the Mountain Lagoon population occurs on Hawkesbury Sandstone, in vegetation dominated by *Eucalyptus punctata* and *Corymbia gummifera*. In western Sydney, *Acacia pubescens* occurs in clay soils, often associated with gravels and ironstones (James et al. 1999).

Threats – road widening and maintenance, weed invasion, low genetic variability due to isolated populations, inappropriate fire regimes, hybridisation, mechanical removal, disease, rubbish dumping (NPWS 2003a).

Conservation Status – Briggs and Leigh (1996) state that this species is adequately represented within Wollemi NP, while Latham (1995) and James (1997) indicate that the species is also present in Scheyville NP and Windsor Downs Nature Reserve, and in Hoxton Park Reserve, all three occuring in western Sydney.

EPBC Act: **Vulnerable**; *TSC Act*: **Vulnerable**; *IUCN (2001)*: **VU A2bc (proposed)**; *ROTAP*: **3VCa**

9. *Acacia subtilinervis* F.Muell. (Fabaceae: Mimosoideae)

Distribution within Wollemi – recorded only above Rocky Creek (near Wolgan) in the west of the park (1970 record, DECC Atlas).

Habitat – Kodela and Harden (2002) state that this species grows in heath and dry sclerophyll forest on rocky outcrops, on the ranges south from the Wolgan River, and on the coast south from Nowra. Tame (1992) indicates that this species grows in gravelly soils in eucalypt forests and woodlands, and is rare in both NSW and Victoria.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list this species as occurring in Tarlo River, Morton, Deua, Morton, Wadbilliga, and Snowy River NPs, all well to the south of Wollemi NP.

EPBC Act: **not listed**; *TSC Act*: **not listed**; *IUCN (2001)*: **LC (proposed)**; *ROTAP*: **3RCa**

10. *Almaleea incurvata* (Cunn.) Crisp & P. Weston (Fabaceae: Faboideae)

Distribution within Wollemi – in the south-west around the Newnes Plateau and adjacent areas, and in the south-east near the Culoul Range in 2004 (DECC Atlas).

Habitat – Typical habitat in the south-west includes areas of localised impeded drainage, supporting hanging swamps of *Leptospermum squarrosum, Lepidosperma forsythii, Lepyrodia scariosa, Epacris obtusifolia, Sphaerolobium minus, Epacris microphylla* var. *microphylla, Grevillea evansiana, Dampiera stricta, Lycopodium laterale, Baumea rubiginosa, Boronia microphylla, Gleichenia dicarpa* and *Pultenaea canescens*. Benson and Keith (1990) have suggested that the location and orientation of these hanging swamps is related to the Deanes Creek and Happy Valley Lineaments which dominate the hydrology of parts of the Newnes Plateau.

Threats – draining of swamp habitat, pollution.

Conservation Status – Briggs and Leigh (1996) list this species as occurring only in Blue Mountains NP. Other records of *Almaleea incurvata* for urban areas of the Blue Mountains (Douglas & Bell in prep.), as well as within conservation reserves; the conservation risk code should be amended to 2RC-.

EPBC Act: **not listed**; *TSC Act*: **not listed**; *IUCN (2001)*: **LC (proposed)**; *ROTAP*: **2RC-t; 2RC- (proposed)**

11. *Apatophyllum constablei* McGillivray (Celastraceae)

Distribution within Wollemi – restricted to the hills around Glen Davis in the southwest. Thirty-two populations are known in this area, each supporting between 10 and 400+ plants (S. Clarke, pers. comm. 2006). Briggs and Leigh (1996) indicate species is known only from this part of Wollemi NP.

Habitat – Associated species at one location in Running Stream catchment south of Gospers Mountain included a canopy of *Eucalyptus consideniana* and *Eucalyptus piperita*, over a scattered shrub layer of *Banksia spinulosa* var. *spinulosa, Leptospermum sphaerocarpum, Pimelea linifolia, Eriostemon hispidulus, Bossiaea rhombifolia* subsp. *rhombifolia, Hibbertia acicularis, Pultenaea echinula, Lasiopetalum parviflorum, Kunzea ambigua, Monotoca scoparia* and *Grevillea sericea*. Ground layer vegetation included *Entolasia stricta, Dampiera stricta, Patersonia glabrata, Poranthera ericifolia, Patersonia sericea,*

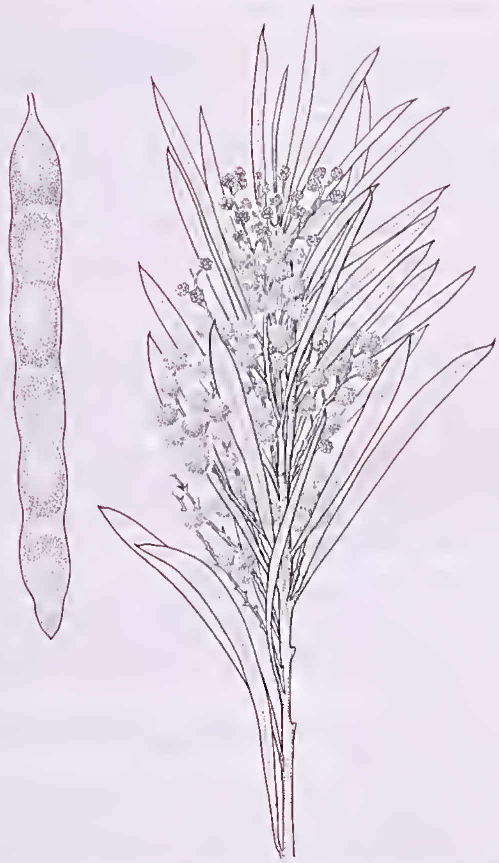

Fig. 4. *Acacia flocktoniae* (illustration by C. Wardrop 2001)

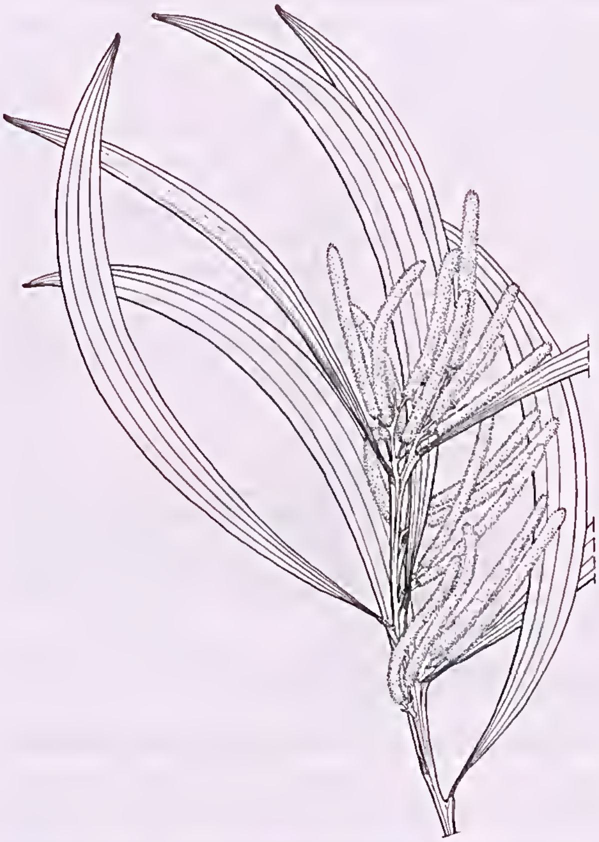

Fig. 6. *Acacia matthewii* (illustration by Don Fortescue)

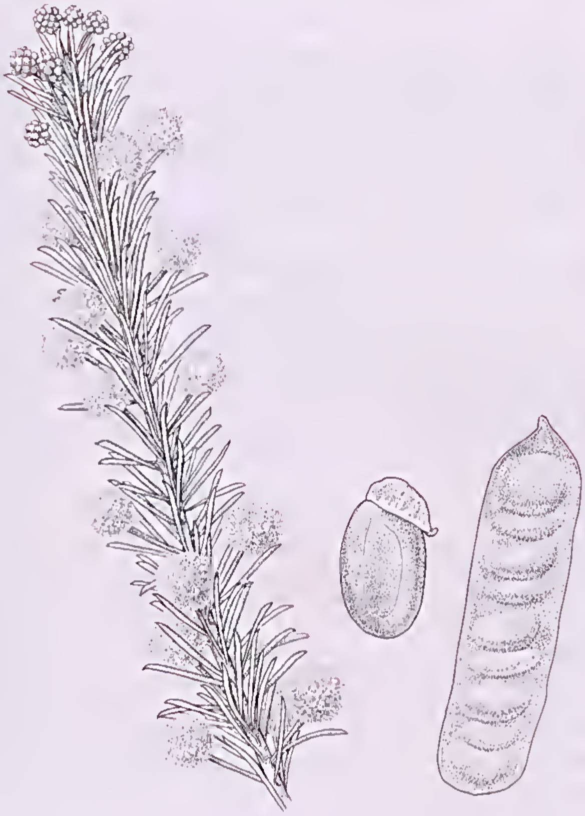

Fig. 5. *Acacia gordonii* (illustration by C. Wardrop 2001)

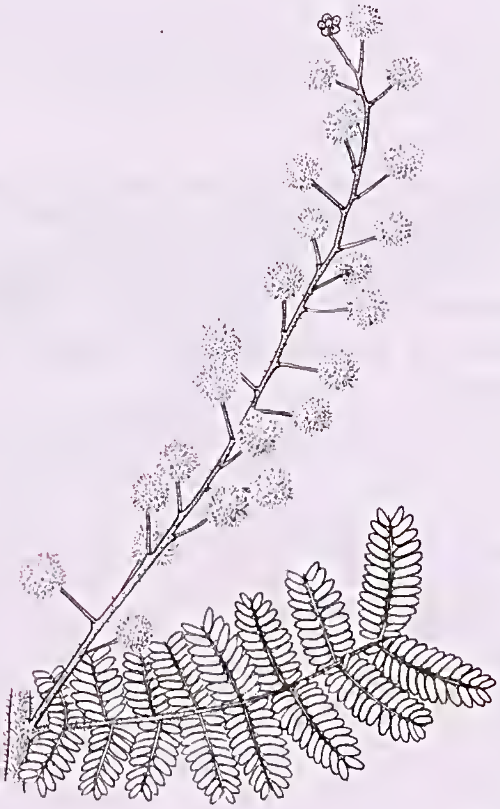

Fig. 7. *Acacia pubescens* (illustration by C. Wardrop 2001)

Lomandra glauca, Lomandra obliqua, Xanthosia atkinsoniana and *Goodenia heterophylla* subsp. *heterophylla*. At this location, around 15–20 plants were scattered on a westerly-facing lower slope on coarse sandstone soils, approximately 3.5 years after a major fire. It is likely that small scattered populations of this species occur on many of the exposed ridges in this part of Wollemi. Cooper (1986) investigated the type location of *Apatophyllum constablei*, and summarised the habitat there as a dry sclerophyll forest of *Eucalyptus piperita* with an understorey of *Banksia serrata, Caustis flexuosa, Petrophile pulchella* and *Grevillea mucronulata*. He also concluded that only 24 plants were present at the type location at the time of his survey. Other reported habitat for this species includes lower slopes in close proximity to streams, particularly in the central Coorongooba Creek area. It is possible that fire is an important factor in the lifecycle of this species, as seedlings have only been observed in areas recently burnt (S. Clarke, pers. comm.).

Threats – no threats identified.

Conservation Status – A Species Recovery Plan has been prepared (Jones & Vollmer 1994); additional information on biology in Cooper (1986). The species has recently been removed from listing under the NSW *TSC Act 1995* due to the finding of large numbers of individuals over an area of 230 km^2 (Scott & Keith 2006). A revised conservation risk code is proposed here.

EPBC Act: **Endangered;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: 2EC-; **2RCa (proposed)**

12. *Asterolasia elegans* L.McDougall & Porteners (Rutaceae)

Distribution within Wollemi – DECC Atlas records for the Morans Rocks area (near Maroota), detailed in Latham (1995).

Habitat – McDougall and Porteners (1990) describe the habitat in north-western Sydney as a sandy soil with underlying yellow clay, on the southern aspect of a steep hillside above a creek in open forest of *Syncarpia glomulifera* and *Eucalyptus piperita*, with an understorey of wet sclerophyll plants. Benson and McDougall (2001) add *Angophora costata, Acmena smithii, Trochocarpa laurina* and *Ceratopetalum apetalum*. Such habitat is widespread in south-eastern Wollemi, and hence potential habitat within the park is widespread.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) indicate adequate populations occur in Marramarra NP in north-western Sydney. Species Recovery Plan prepared by Scott (1994).

EPBC Act: **Endangered;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN C2b (proposed);** *ROTAP*: **2ECa**

13. *Atkinsonia ligustrina* (Cunn. ex F.Muell.) F.Muell. (Loranthaceae)

Distribution within Wollemi – occurs in the Newnes Plateau area in the south-west; around the Colo/Capertee River junction and the Culoul Range in the south-east.

Habitat – Quirico (1992) states that this species grows in woodland and heath in exposed sites, a single plant often parasitic on the roots of several nearby plants. Maryott-Brown and Wilks (1993) indicate that this species occurs in low open woodland dominated by *Eucalyptus sieberi, E. piperita, Allocasuarina distyla* and *Banksia serrata*. Of additional interest for Wollemi populations is the occurrence of *Atkinsonia ligustrina* on deep sandy substrates in the Mellong Swamps, in south-eastern Wollemi. Here the species occurs in an open woodland of *Angophora costata, Banksia serrata* and *Corymbia gummifera*, with a well developed understorey of *Acacia ulicifolia, Brachyloma daphnoides, Phyllota phylicoides, Pteridium esculentum, Conospermum taxifolium, Lomandra glauca, Entolasia stricta* and *Hibbertia fascicularis*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list occurrence in Blue Mountains and Wollemi NPs, although populations there are of unknown size and status.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RCa**

14. *Baeckea kandos* A.R.Bean (Myrtaceae)

Distribution within Wollemi – only known from Dunns Swamp (Kandos Weir) in the north-west.

Habitat – Bean (1997) describes the habitat of the species as heathland or shrubland on skeletal sandstone soils, associated with *Leptospermum parvifolium, Leptospermum arachnoides* and *Grevillea diffusa*. The total population has been estimated at fewer than 100 plants. Bean (1997) indicates that searches of apparently suitable habitat in the vicinity of the known population have not revealed further specimens; none were recorded elsewhere in Wollemi (Bell 1998).

Threats – no threats identified.

Conservation Status – *Baeckea kandos* [syn. *Baeckea sp. 6 (Kandos)* and *Baeckea sp. E*] occurs only within Wollemi NP. In his description of the species, Bean (1997) discusses *Baeckea kandos* as endangered, with only two small populations known a few hundred metres apart near Dunns Swamp.

EPBC Act: **Endangered;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN D1 (proposed);** *ROTAP*: **2RC-t**

15. *Banksia penicillata* (A.S.George) K.R. Thiele (Proteaceae)

Distribution within Wollemi – recorded as far north as Benjang Gap in the north-west of the park, with good populations around Hefrons Gap and the northern end of the Newnes Plateau. It is generally widespread along the western sections of Wollemi, from the Lee Creek area, south to the Newnes Plateau (S. Clarke, pers. comm. 2006).

Habitat – In the Wolgan Lookout and Deanes Creek areas, *Banksia penicillata* is scattered within habitat dominated by *Eucalyptus consideniana, E. punctata, E. sparsifolia, E. sclerophylla, Bossiaea rhombifolia* subsp. *rhombifolia, Dodonaea triquetra, Exocarpus strictus, Acacia terminalis, Leucopogon muticus, Grevillea mucronulata, Podolobium ilicifolium, Leptospermum trinervium, Dillwynia phylicoides, Grevillea sericea, Lomandra glauca, Patersonia glabrata, Caustis flexuosa* and *Lomandra confertifolia* subsp. *rubiginosa*. Near Cyrils Rocks further to the north, *Banksia penicillata* occurs in a mallee heathland of *Eucalyptus bensonii, Allocasuarina distyla, A. nana, Boronia floribunda, Kunzea ambigua, Grevillea buxifolia, Grevillea evansiana, Isopogon anethifolius, Leptospermum arachnoides, Dillwynia acicularis, Schoenus imberbis, Laxmannia gracilis, Lepidosperma viscidum, Lomandra glauca, Chloanthes stoechadis* and *Patersonia sericea*. On the deeper sands around Hefrons Gap, this species is present on slopes and ridges within an open forest of *Eucalyptus rossii, E. punctata, E. sparsifolia, Leucopogon muticus, Leptomeria acida, Bossiaea heterophylla, Monotoca scoparia, Pultenaea microphylla, Podolobium ilicifolium, Brachyloma daphnoides, Pomax umbellata, Aristida ramosa, Hibbertia circumdans, Patersonia sericea* and *Phyllanthus hirtellus*. In the more sheltered gullies associated with pagoda rock formations, it also occurs in open forest of *Eucalyptus piperita, Pteridium esculentum, Acacia longifolia, A. parvipinnula, Leptospermum polyanthum, Leucopogon lanceolata* var. *lanceolatus, Gonocarpus teucrioides* and *Stellaria pungens*. Outside of Wollemi, Washington (2001a) indicates that this species is the dominant taxon in heath, scrub, woodland and forest vegetation in Gardens of Stone NP.

Threats – no threats identified.

Conservation Status – *Banksia penicillata* was formerly included as a variety in *Banksia conferta* and listed as 3RC- by Briggs and

Leigh (1996). These authors list *Banksia conferta* as occurring within Lamington, Mount Barney, Ngungun, and Tibrogargan NPs (all in Queensland), as well as Wollemi NP in New South Wales. Of these, it is likely that only Wollemi NP supports populations of *B. penicillata*. Washington (2001a) has recorded *Banksia penicillata* in several parts of Gardens of Stone NP to the south-west of Wollemi, and suggests that there are several thousand plants conserved there. Bell (2001) suggested that the conservation risk code for this species be amended to 3RCa to reflect the extent of conserved populations.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: 3RC-; **3RCa (Bell 2001)**

16. *Blechnum gregsonii* (Watts) Tind. (Blechnaceae)

Distribution within Wollemi – likely to be present in rainforest gullies in the south of the park.

Habitat – Wilson (1990) states that this species grows in cool rainforests mainly in the Blue Mountains and Illawarra coastal ranges. Extensive areas of this habitat type are present within the Wollemi-Blue Mountains wilderness; it may be assumed that this species is represented there.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list this species as occurring in Blue Mountains, Wollemi, and Budderoo NPs; only in Wollemi is it considered to be adequately conserved.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **2RCa**

17. *Boronia barkeriana* F.Muell. subsp. *barkeriana* (Rutaceae)

Distribution within Wollemi – disjunct locations between Kekeelbon Mountain and Mt Coricudgy, in the central sections of the Park.

Habitat – Duretto (2003) indicates it is usually found in heath in damper areas.

Threats – no threats identified.

Conservation Status – Duretto (2003) has reviewed the taxonomy of *Boronia barkeriana*, defining three subspecies. Subspecies *barkeriana* is apparently restricted to the Blue Mountains with disjunct locations between Kekeelbon Mountain and Mt Coricudgy. Duretto (2003) indicates that the most recent collection dates back to the 1960s, and for this reason has applied a conservation risk code of 2RC- until further field research can be undertaken.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **2RC- (Duretto 2003)**

18. *Boronia floribunda* Sieber ex Spreng. (Rutaceae)

Distribution within Wollemi – Deanes Creek and Cyrils Rock areas north of the Newnes Plateau, as well as the Kekeelbon Mountains, Mt Coricudgy, Gospers Mountain and Glen Davis (Duretto 2003).

Habitat – In the Deanes Creek area *Boronia floribunda* occurs within open forest of *Eucalyptus sclerophylla, E. consideniana, E. sparsifolia, Dillwynia phylicoides, Caustis flexuosa, Bossiaea rhombifolia* subsp. *rhombifolia, Boronia microphylla, Leptospermum sphaerocarpum, Grevillea sericea, Kunzea ambigua, Gahnia filifolia, Mitrasacme polymorpha, Lepidosperma laterale, Hibbertia serpyllifolia* and *Xanthosia atkinsoniana*. Near Cyrils Rocks further to the north, *Boronia floribunda* occurs in a mallee heathland of *Eucalyptus bensonii, Banksia penicillata, Allocasuarina distyla, Allocasuarina nana, Kunzea ambigua, Grevillea buxifolia, Grevillea evansiana, Isopogon anethifolius, Leptospermum arachnoides, Dillwynia acicularis, Schoenus imberbis, Laxmannia gracilis, Lepidosperma viscidum, Lomandra glauca, Chloanthes stoechadis* and *Patersonia sericea*.

Threats – no threats identified.

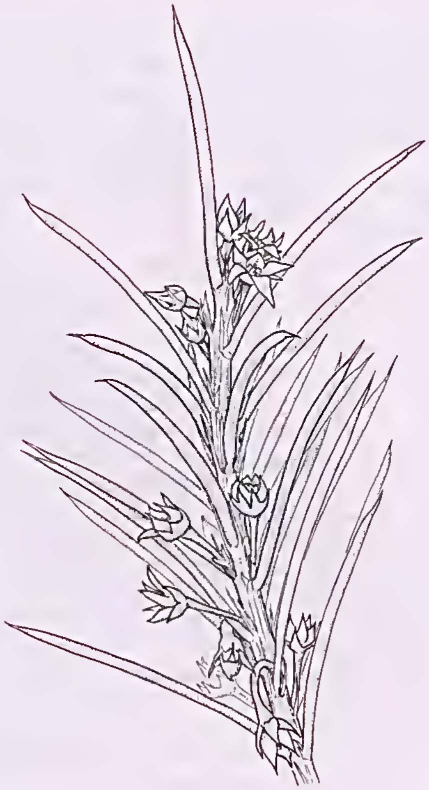

Fig. 8. *Apatophyllum constablei* (illustration by Lesley Elkan. 2002)

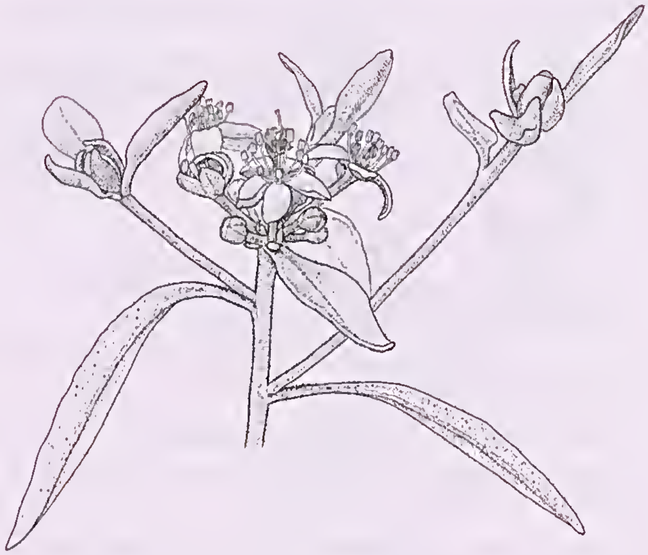

Fig. 9. *Asterolasia elegans* (illustration by Lesley Elkan 2002)

Conservation Status – confined to the Sydney region in heath and sclerophyll forest on sandstone (Weston & Duretto 2002). Duretto (2003) considers that a conservation risk code of 2RC- is appropriate, given its limited distribution. Reserved populations known from Garigal, Ku-ring-gai Chase, Blue Mountains, Royal and Nattai NPs (Benson & McDougall 2001).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RC- (Duretto 2003)**

19. *Boronia fraseri* Hook. (Rutaceae)

Distribution within Wollemi – occurs in the south-east of the Park.

Habitat – Benson and McDougall (2001) cite habitat for *Boronia fraseri* as gullies supporting moist eucalypt open forest (with *Acacia elata*) and margins of gallery rainforest (with *Ceratopetalum apetalum*, *Tristaniopsis laurina*). Along the Culoul Range in south-eastern Wollemi, *Boronia fraseri* occurs in an open forest of *Corymbia eximia*, *Eucalyptus sparsifolia* and *E. piperita*, over an understorey of *Dillwynia floribunda* var. *teretifolia*, *Leptospermum trinervium*, *Dillwynia acicularis*, *Boronia ledifolia*, *Persoonia linearis*, *Platysace linearifolia*, *Grevillea buxifolia* subsp. *buxifolia*, *Lissanthe sapida*, *Stylidium productum*, *Hibbertia obtusifolia*, *Lomandra glauca* and *Patersonia glabrata*. *E. sparsifolia*, *Acacia buxifolia*, *Leucopogon muticus*, *Persoonia linearis*, *Goodenia decurrens*, *Philotheca salsolifolia*, *Dodonaea boronifolia*, *Lisanthe strigosa*, *Stypandra glauca*, *Goodenia heterophylla* subsp. *heterophylla*, *Patersonia sericea*, *Pomax umbellata*, *Stackhousia muricata*, *Hybanthus monopetalus*, *Joycea pallida*, *Cleistochloa rigida* and *Lomandra multiflora* subsp. *multiflora* in the Lee Creek catchment and along the northern escarpment of the park.

Threats – no threats identified.

Conservation Status – listed for Goulburn River and Wollemi NPs (adequate representation), and Kanangra-Boyd and Gibraltar Range NPs (unknown status and size)(Briggs and Leigh 1996); also present in crown land adjacent to Manobalai Nature Reserve (Bell 1997a), and likely to also occur within that reserve.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RCa**

21. *Brasenia schreberi* Gmelin. (Cabombaceae) Watershield

Distribution within Wollemi – recorded in the Central Colo area in 1975, 1977 and 1989 (DECC atlas), but it is unclear whether these populations occur within the present Park boundaries.

Habitat – water bodies, shallow freshwater lagoons and backwaters of rivers (Fairley 2004).

Threats – draining of swamp habitats, pollution.

Conservation Status – Briggs and Leigh (1996) list this species as occurring only in Crowdy Bay NP, although it is present in many other areas. James (1997) also adds Thirlmere Lakes NP.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **3RC-+**

22. *Callistemon shiressii* Blakely (Myrtaceae)

Distribution within Wollemi – along Colo River and catchments in the south-east.

Habitat – in sheltered forest adjacent to creeks on alluvial soils, in habitat dominated by *Eucalyptus michaeliana*, *E. crebra* and *Syncarpia glomulifera*, over an understorey of *Backhousia myrtifolia*, *Bursaria spinosa*, *Podolobium ilicifolium*, *Acacia filicifolia*, *Dianella caerulea* and *Entolasia stricta*, in Yengo and Wollemi NPs (Maryott-Brown & Wilks 1993).

Threats – no threats identified.

Conservation Status – listed for Yengo and Wollemi NPs (Briggs & Leigh 1996); other records for Brisbane Water NP (Benson & Fallding 1981), Jilliby State Conservation Area and Watagans NP (unpubl. data) and the State Forests around Wyong (Bell 2002a). The northern limit of the species is Bow Wow Gorge near Quorrobolong in Cessnock LGA (Bell & Murray 2001).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RC-**

23. *Cynanchum elegans* (Benth.) Domin. (Asclepiadaceae) White Cynanchum

Distribution within Wollemi – a collection from the headwaters of Doyles Creek in the east of the park is the first confirmed record for Wollemi NP (Bell 1998).

Habitat – at Doyles Creek, occurs in moist open forest on a sheltered upper slope, where dominant species include *Eucalyptus piperita*, *Syncarpia glomulifera*, *Allocasuarina torulosa* and *Angophora floribunda*, over a sparse understorey of *Rapanea variabilis*, *Polyscias sambucifolia*, *Indigofera australis* and a dense ground layer of *Blechnum cartilagineum* and *Pteridium esculentum*. It is possible that this species occurs in many of the sheltered gullies of the park, although the level of survey undertaken to date would suggest that populations are not widespread. In south-eastern Wollemi along the Culoul Range, *Cynanchum elegans* also occurs on ridgetop remnants of Wianamatta Shale, in open forest of *Eucalyptus crebra*, *E. eugenioides*, *E. punctata* and *E. beyeriana*. Understorey vegetation comprises *Acacia parramattensis*, *Syncarpia glomulifera*, *Bursaria spinosa*, *Exocarpus strictus* and *Rapanea variabilis*, over a dense ground layer of *Pratia purpurascens*, *Lomandra filiformis*, *Goodenia heterophylla subsp. heterophylla*, *Dianella caerulea*, *Galium binifolium* and *Poranthera microphylla*.

Threats – fire impacting on rainforest habitats.

Conservation Status – Copeland and Hunter (1999) have suggested a revised code of 3VCi, to reflect new populations found in recent years, but the majority of populations are small, and it is better retained as 3ECi (Bell 2001). A Species Recovery Plan has been prepared (Matthes & Nash 1993). Other confirmed populations are Camels Hump Nature Reserve and Woko NP (Briggs & Leigh 1996), Goulburn River NP (McRae & Cooper 1985), and Glenrock SRA and Booti Booti NP (M.Schroder, NPWS, pers. comm.). James (1997) also reports findings around Richmond in western Sydney.

EPBC Act: **Endangered;** *TSC Act*: **Endangered;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **3ECi; 3VCi (Copeland & Hunter 1999); 3ECi (Bell 2001)**

24. *Cyphanthera scabrella* (Benth.) Miers (Solanaceae)

Distribution within Wollemi – DECC Atlas record from 1977 for near Bilpin in the south of Wollemi, although no further details on habitat at this sites are known.

Habitat – Conn (1992a) states that this species grows in dry or wet sclerophyll forest in sandstone-derived soil, in the Bilpin-Mt Wilson area of the Blue Mountains. Benson and McDougall (2001) note that it occurs on rocky slopes in eucalypt forest bordering creekside rainforest, with *Ceratopetalum apetalum* and *Doryphora sassafras*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list this species only for Blue Mountains NP.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **2RC-**

25. *Darwinia peduncularis* B.Briggs (Myrtaceae)

Distribution within Wollemi – from the Mt Iris to Mt Boonbourwa area in the west of Wollemi (S. Clarke, pers. comm. 2006).

Habitat – exposed ridgelines above Wollemi Creek in the centre of the park, in an open woodland/ heath of *Eucalyptus rossii, E. bensonii* and *E. multicaulis*, with a variety of shrubs including *Leptospermum parvifolium, Leucopogon muticus, Leptospermum trinervium, Calytrix tetragona, Baeckea densifolia, Leptospermum sphaerocarpum, Leptospermum arachnoides, Caustis flexuosa, Acacia linifolia, Bossiaea heterophylla* and *Dillwynia retorta*. Other populations in this area occur in sheltered locations in an open forest of *Eucalyptus consideniana* and *E. piperita*, with *Hakea dactyloides, Leptospermum trinervium, Dillwynia retorta, Gompholobium virgatum, Persoonia oblongata, Styphelia tubiflora, Isopogon anemonifolius, Lomatia silaifolia, Monotoca scoparia, Lomandra obliqua, Stylidium productum* and *Caustis flexuosa*. *Darwinia peduncularis* is locally common in this area, and appears to be sporadically distributed in the remote parts of the park.

Threats – no threats identified.

Conservation Status – listed for Blue Mountains, Wollemi, and Marramarra NPs (Briggs & Leigh 1996).

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RCi**

26. *Diuris* sp. aff. *punctata* (Colo River) (Orchidaceae)

Distribution within Wollemi – Bishop (2000) describes a purple flowered *Diuris* from the Mellong Range area in the south-eastern section of the park.

Habitat – occurs on swamp fringes growing in heathland or heathy sclerophyll forest, in peaty, gravelly soils.

Threats – illegal removal of plants by orchid enthusiasts, fire during flowering season.

Conservation Status – other records are mentioned by Bishop (2000) for the Hunter Valley. While no estimate is made of its conservation status, the low number of records would suggest that it may be a species of quite restricted distribution.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **not listed; 2KC (proposed)**

27. *Epacris coriacea* Cunn. ex DC. (Epacridaceae)

Distribution within Wollemi – recorded at several locations in the upper reaches of Wollemi Creek.

Habitat – grows in skeletal sandy soils on sandstone cliffs and in rock crevices on the Woronora Plateau, and west to Bare Rock near Rylstone (Powell 1992). At upper Wollemi Creek, it occurs in an open forest of *Eucalyptus rossii* and *Corymbia gummifera*, with an understorey of species such as *Leptospermum trinervium, Banksia spinulosa* var. *spinulosa, Persoonia levis, Dillwynia floribunda* var. *floribunda, Dillwynia retorta, Gompholobium virgata* subsp. *aspalathoides, Patersonia glabrata, Caustis flexuosa, Bossiaea heterophylla, Xanthosia atkinsoniana* and *Lomandra glauca*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list occurrence in Budderoo, Wollemi, and Macquarie Pass NPs, although there are no details on the extent and status of their populations.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **3RC-**

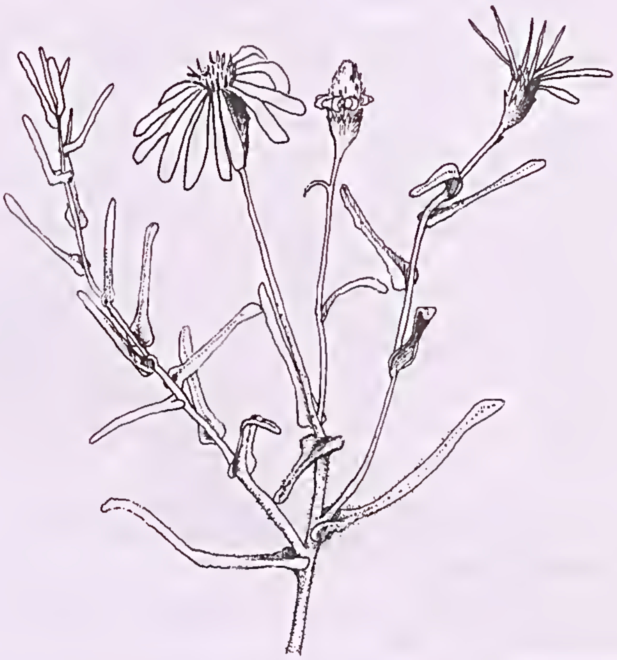

Fig. 10. *Olearia cordata* (illustration by Helen Bryant)

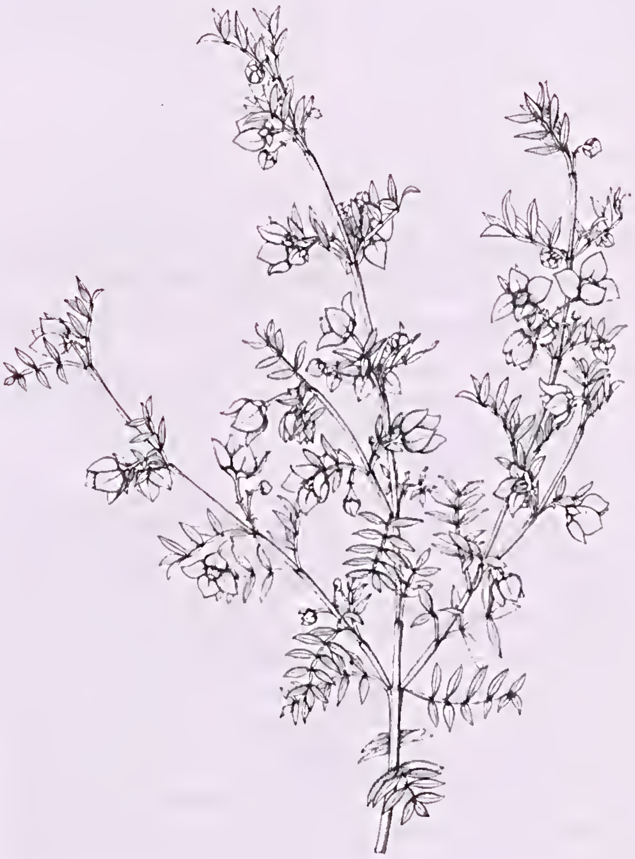

Fig. 11. *Boronia floribunda* (illustration by M. Maiden)

28. *Epacris muelleri* Sonder (Epacridaceae) Mueller's Heath

Distribution within Wollemi – recorded on damp rock faces in the southern and south-western sections of the park, around Mt Irvine and Glen Davis; also in the central portion near the Kekeelbon Mountains, Mt Duran Duran, Cyrils Rocks, and Dunns Swamp (Kandos Weir).

Habitat – near Box Hole Clearing, it occurs on rocky outcrops in a mallee heathland with *Eucalyptus bensonii, Kunzea ambigua, Boronia floribunda, Allocasuarina distyla, Allocasuarina nana, Grevillea buxifolia* subsp. *ecorniculata, Caustis pentandra, Isopogon anethifolius, Banksia conferta, Goodenia decurrens, Dampiera stricta, Schoenus imberbis* and *Actinotus minor*. Further to the south near Wolgan Lookout, *Epacris muelleri* occurs within a sheltered open forest of *Eucalyptus piperita, E. cypellocarpa, Angophora floribunda* and *Eucalyptus punctata*, with an understorey of *Acacia terminalis, Persoonia linearis, Acacia obtusifolia, Podolobium ilicifolium, Leucopogon muticus, Platysace lanceolata, Dodonaea triquetra, Lomandra longifolia, Stypandra glauca* and *Lepidosperma laterale*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list only for Wollemi and Blue Mountains NPs; recently recorded in Gardens of Stone NP (Washington 2001a).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **3RC-**

29. *Eucalyptus aenea* K.Hill (Myrtaceae)

Distribution within Wollemi – a single population of around 40 plants recorded on the extreme northern boundary of the park near Denman (V. Klaphake, per. comm. 2007).

Habitat – Hill (1997b) describes the habitat for this species as shallow soils on the higher flanks of low sandstone ridges, with *Eucalyptus sideroxylon, E. sparsifolia* and *E. fibrosa*. Understorey vegetation is composed of a variety of scleromorphic shrub species.

Threats – indiscriminate clearing by adjacent land-owners.

Conservation Status – Hill (1997b) suggested conservation code of 2RC, reflecting the presence within Goulburn River NP. Other small populations occur in Manobalai Nature Reserve (Bell 2001).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2RC (Hill 1997b); 2RC- (Bell (2001)**

30. *Eucalyptus bensonii* L.A.S.Johnson & K.Hill (Myrtaceae)

Distribution within Wollemi – all known occurences of *Eucalyptus bensonii* are in the south-western and central sections of Wollemi, in the area north of Glen Davis between Cyrils Rocks and Box Hole Clearing, east to around Mt Monundilla.

Habitat – most prevalent in heathland with emergent mallee eucalypts or on resistant sandstone platforms, in skeletal sandy soils derived from Narrabeen Sandstone. At one site near Box Hole Clearing, an unusual and unique small ridgeline of very resistant sandstone supports mallee heathland for its entire length, with species such as *Eucalyptus multicaulis, E. laophila, Allocasuarina distyla, A. nana, Boronia floribunda, Kunzea ambigua, Dampiera stricta, Dillwynia acicularis, Platysace lanceolata, Schoenus imberbis, Laxmannia gracilis, Grevillea buxifolia* subsp. *ecorniculata, Actinotus minor, Caustis pentandra, Lepidosperma viscidum, Grevillea evansiana, Lomandra glauca, Leptospermum arachnoides, Isopogon anethifolius* and *Acacia suaveolens*. At another location in the upper Wollemi Creek catchment, approximately five individuals were recorded on an exposed sandstone platform surrounded by an open forest of *Eucalyptus sparsifolia, E. piperita*, and *E. punctata*, with an understorey of *Acacia longifolia, Prostanthera prunelloides, Leptospermum sphaerocarpum, Persoonia linearis, Podolobium ilicifolium, Lomatia silaifolia, Pomaderris ledifolia, Lepidosperm gunnii, Stylidium productum, Pteridium esculentum, Lepidosperma urophorum* and *Lomandra confertifolia* subsp. *rubiginosa*. A further sandstone platform 7km east of Hanging Rock supported a few scattered individuals of *Eucalyptus bensonii*, with this location representing the eastern limit of the species. Vegetation here comprised an open woodland/ heath of *Eucalyptus rossii* and *E. multicaulis*, with a variety of shrubs including *Leptospermum parvifolium, Leucopogon muticus, Leptospermum trinervium, Calytrix tetragona, Baeckea densifolia, Leptospermum sphaerocarpum, L. arachnoides, Caustis flexuosa, Acacia linifolia, Bossiaea heterophylla* and *Dillwynia retorta*. It is likely that scattered individuals of this species occur on most of the many sandstone platforms within the central and south-western sections of Wollemi, much of which is remote.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list only Wollemi NP; no other records are known.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2RCt**

31. *Eucalyptus burgessiana* L.A.S.Johnson & Blaxell (Myrtaceae) Faulconbridge Mallee

Distribution within Wollemi – approximately 20 plants between Mountain Lagoon and Mt Irvine reported in 2001 (DECC Atlas), and several tens of plants on a ridge near Tootie Creek east of Mountain Lagoon.

Habitat – near Mountain Lagoon, *Eucalyptus burgessiana* co-dominates low mallee scrub and open forest on skeletal sandstone soils with *Eucalyptus piperita, Corymbia gummifera* and *Eucalyptus consideniana*. Understorey species include *Petrophile pulchella, Hakea dactyloides, Leptospermum trinervium, Dillwynia elegans, Phyllota grandiflora, Bossiaea heterophylla, Platysace linearifolia* and *Lambertia formosa* in the shrub layer, and *Lomandra glauca, Schoenus imberbis, Lepyrodia scariosa, Patersonia sericea, Cyathochaeta diandra, Caustis flexuosa* and *Lomandra gracilis* on the ground. A second stand of mallee also occurs in deep sandy alluvium in an unusual gully floor situation below this ridge, where *E. burgessiana* co-occurs with *Leptospermum trinervium* and a variety of other shrubs.

Threats – no threats identified.

Conservation Status – recorded only from Blue Mountains NP (Briggs & Leigh 1996), but recent records in southern Wollemi have extended the northern distribution limit.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2RCa**

32. *Eucalyptus cannonii* R.T. Baker (Myrtaceae) Capertee Stringybark

Distribution within Wollemi – between Wolgan and Dunns Swamp (Kandos Weir) along the western escarpment of the park.

Habitat – in most cases, individuals are scattered in mixed eucalypt forest typically dominated by *Eucalyptus punctata, E. rossii, E. sparsifolia* and *Angophora floribunda*. Understorey vegetation is dominated by *Podolobium ilicifolium, Acacia buxifolia, Bossiaea obcordata, Banksia cunninghamii subsp. cunninghamii, Monotoca scoparia, Lomandra glauca, Pomax umbellata* and *Lomandra multiflora*. Other occurences are known from open forest of *Eucalyptus dawsonii, E. cypellocarpa* and *E. punctata* in footslope positions. Washington (2001b) recorded this species in a range of similar habitats in the adjacent Gardens of Stone NP, generally within open forest of species such as *Eucalyptus rossii, E. tenella, E. fibrosa, E. punctata, E. ligustrina, E. macrorhyncha, E. eugenioides, E. melliodora, E. albens, E. crebra, E. polyanthemos* and *E. praecox*.

Threats – no threats identified.

Conservation Status – also known from Avisford Nature Reserve (Bell 1995), Pantoney's Crown Nature Reserve (Benson & Keith 1990), Winburndale Nature Reserve and Gardens of Stone NP (Hunter & White 1999; Washington 2001a), Newnes and Ben Bullen State Forests (Forestry Commission of NSW 1987). Hunter and White (1999) have discussed in detail the distribution and conservation status of *Eucalyptus cannonii*, and suggest that this species be delisted from the NSW TSC Act in recognition of substantial populations in several reserves, and lowered clearing threats. They also suggest a revision of the conservation risk code to 2RCa, which seems justified. Washington (2001b) has undertaken a detailed survey of this species within the Gardens of Stone NP, with the aim of determining population sizes currently conserved. He estimated around 2000–3000 plants for that reserve and a total of 10 000–15 000 for the region, but also indicated that the majority of specimens attributable to *Eucalyptus cannonii* are potentially hybrids with *Eucalyptus macrorhyncha*.

EPBC Act: **Vulnerable;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2VCi; 2RCa (Hunter & White 1999)**

33. *Eucalyptus corticosa* L.A.S. Johnson (Myrtaceae)

Distribution within Wollemi – occurs west of Mt Coricudgy with some plants within the park boundary near Dunns Swamp (A. Fairley, *pers. comm.*).

Habitat – sclerophyll woodland on shallow, infertile sandy soils in the upper reaches of the Cudgegong River, often associated with *Eucalyptus rossii* (DECC).

Threats – clearing for agriculture or road maintenance, inappropriate fire regimes.

Conservation Status – known only within an area of 20 km^2 around Mt Coricudgy; not known how extensive the population is within Wollemi.

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2VC- (proposed)**

34. *Eucalyptus fergusonii* subsp. *dorsiventralis* L.Johnson & K.Hill (Myrtaceae)

Distribution within Wollemi – recorded along the Tootie Track north of Mountain Lagoon, representing a southerly range extension.

Habitat – on the western end of the Culoul Range near the Colo River, this species occurs on a lower hillslope on shale-influenced soils in an open forest with *Eucalyptus paniculata* subsp. *paniculata*, *E. racemosa*, *E. punctata* and *Syncarpia glomulifera*. Understorey vegetation comprises *Backhousia myrtifolia*, *Notelaea venosa*, *Bursaria spinosa*, *Acacia parramattensis*, *Pultenaea scabra*, *Entolasia stricta*, *Lomandra filiformis* subsp. *filiformis*, *Galium binifolium*, *Asplenium flabellifolium* and *Lomandra longifolia*. The species is also present within the north-eastern sections of the park, although no recent records could be located. In the adjacent Yengo NP, Maryott-Brown and Wilks (1993) summarise the habitat for this taxon as dry sclerophyll forest on Narrabeen Sandstone ridges, usually in saddles or benches near ridgetops, where underlying shale becomes evident. Associated species include *Eucalyptus fibrosa*, *E. sparsifolia*, *Cassinia cunninghamii* and *Podolobium ilicifolium*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list only Wollemi NP, although it also occurs in the adjacent Yengo NP (Bell, Vollmer and Gellie 1993; Maryott-Brown and Wilks 1993), and several other locations in the Hunter Valley (Bell 2001). Good stands of the species also occur in recent additions to Werakata NP near Cessnock (Bell & Driscoll 2007). Bell (2001) has suggested that the conservation risk code be revised to 2RCa or 3RCa, depending on confirmation of specimens collected around Newcastle. This has now been done, and the opportunity is taken here to suggest that the code be revised to 3RCa.

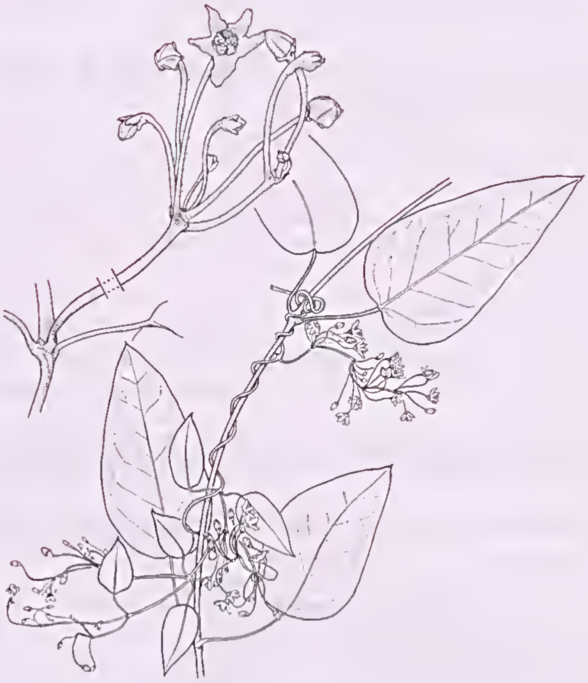

Fig. 12. *Cynanchum elegans* (illustration by Lesley Elkan 2002)

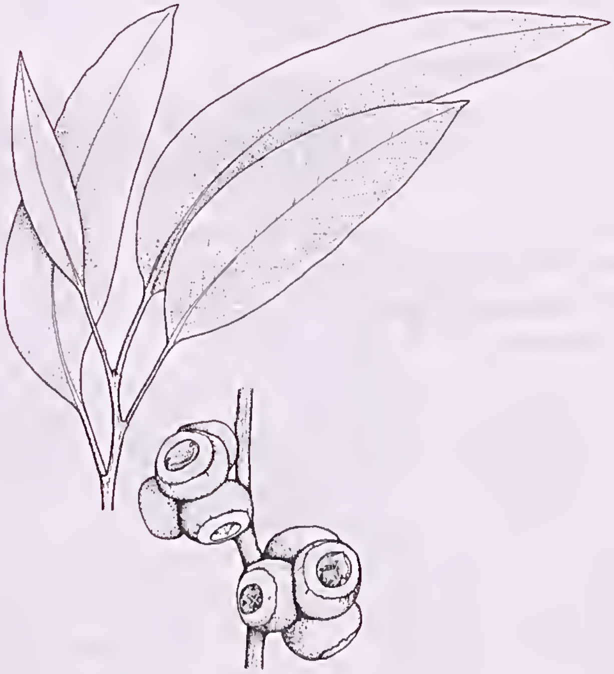

Fig. 13. *Eucalyptus bensonii* (Illustration by David Mackay)

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RC-; 3RCa (proposed)**

35. *Eucalyptus gregsoniana* L.A.S.Johnson & Blaxell (Myrtaceae) Wolgan Snow Gum

Distribution within Wollemi – a small number of records for the Newnes Plateau (Fairley 2004).

Habitat – in poorly-drained heath on the Newnes Plateau, also Clarence-Blackheath area (Benson & Keith 1990). Population sizes in Wollemi are not known.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list this species for Wollemi and Morton NPs, with adequate representation considered only for the latter.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **3RCa**

36. *Eucalyptus hypostomatica* L.A.S.Johnson & K.Hill (Myrtaceae)

Distribution within Wollemi – a small population discovered along the Elcom Trail in the north-east of the park in 2005. More recent investigations revealed a substantial population of an unusual mallee-like stand along a broad ridgeline. Unconfirmed specimens of *Eucalyptus hypostomatica* were also collected from a sheltered gully during fire fighting activities in the Blackwater Creek area several kilometres to the west in the late 1990s. There are no other recent records within Wollemi, although Johnson and Hill (1990) do mention the species for the Widden Brook area.

Habitat – the Elcom trail population occurred within a sheltered gully head where it was locally dominant. Other species present included *Eucalyptus melliodora* (in an interesting disjunct occurrence), *E. punctata, E. sparsifolia, Backhousia myrtifolia, Stenocarpus salignus, Pittosporum undulatum, Notelaea longifolia* and *Acacia prominens*. On the broad ridgeline nearby, other associated species were *Eucalyptus punctata, E. sparsifolia* and *E. fibrosa*.

Threats – no threats identified.

Conservation Status – listed only for Yengo NP by Briggs and Leigh (1996); also from Nattai River and Laceys Creek, in Nattai and Blue Mountains NPs (Fisher et al. 1995); also in Watagans NP near Newcastle (Bell 2002b).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RC-**

37. *Eucalyptus prominula* L.A.S. Johnson & K.D. Hill (Myrtaceae)

Distribution within Wollemi – recorded at the western end of the Culoul Range in south-eastern Wollemi, occuring on a ridgeline in dry sclerophyll forest, extending the known geographical range of the species. Given the extent of new populations recently located in Yengo NP and around the township of Putty (pers. obs 2007), it is likely that sizeable populations also exist in Wollemi.

Habitat – within the adjacent Yengo NP, *Eucalyptus prominula* co-dominates the canopy with *Eucalyptus sparsifolia, Corymbia gummifera, Syncarpia glomulifera* subsp. *glomulifera, Angophora costata* and *Allocasuarina torulosa*. Understorey vegetation includes *Dodonaea triquetra, Podolobium ilicifolium, Acacia terminalis, Persoonia linearis, Platysace linearifolia, Acacia linifolia, Themeda australis, Joycea pallida, Lepidosperma laterale, Phyllanthus hirtellus, Opercularia diphylla, Stackhousia viminea* and *Panicum simile*. To the east of Cessnock in Hunter Valley, *Eucalyptus prominula* occurs on low sandstone ridges with *Corymbia eximia* and *Angophora costata*, over *Dillwynia retorta, Podolobium ilicifolium, Bossiaea obcordata, Joycea pallida, Xanthorrhoea johnsonii, Entolasia stricta, Lomandra cylindrica* and *Lomandra obliqua*.

Threats – no threats identified.

Conservation Status – known from Yengo NP, and several State Forests in the Hunter Region (Bell et al. 1993; Bell 2001). Revised code to 2RC- has been suggested by Bell (2001).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2KC-; 2RC- (Bell 2001)**

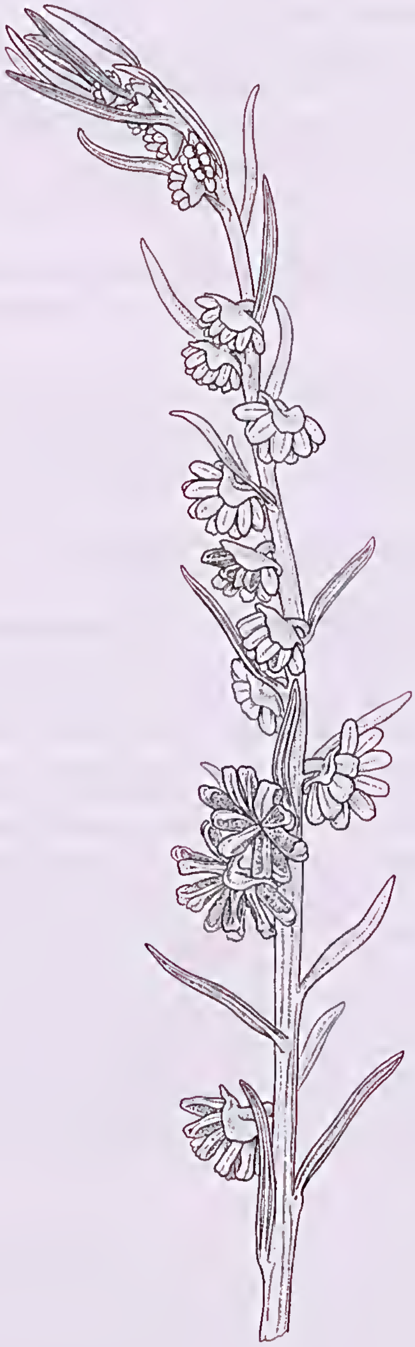

Fig. 14: *Gyrostemon thesioides* (illustration by Lesley Elkan 2004)

38. *Eucalyptus* sp. aff. *eugenioides* (Bees Nest Ridge) (Myrtaceae) A Stringybark

Distribution within Wollemi – Hunter Range in the east of the park.

Habitat – occurs as an emergent with *Eucalyptus deanei* in gullies, over a closed canopy of *Backhousia myrtifolia, Acmena smithii, Acacia prominens, Acacia parvipinnula* and *Syncarpia glomulifera*. The lower stratum consists of a sparse shrub layer of *Notelaea longifolia forma intermedia, Pittosporum revolutum, Cyathea australis,* and *Ficus coronata*, over a dense ground layer of *Calochlaena dubia, Blechnum cartilagineum, Adiantum aethiopicum, Polystichum australiense, Doodia aspera, Oplismenus imbecillus, Dichondra repens, Commelina cyanea, Echinopogon ovatus, Microlaena stipoides,* and *Viola hederacea*. Vines such as *Sarcopetalum harveyanum* and *Marsdenia rostrata*, and epiphytic orchids such as *Plectorrhiza tridentata* are also present.

Threats – no threats identified.

Conservation Status – a tall tree of sheltered forests bearing some resemblance to *Eucalyptus eugenioides*, although differing from that species in the strongly exerted and narrow valves on the fruit (Binns 1996; *pers. obs.*). Previously known only from very localised stands in the Bees Nest Ridge area of Pokolbin State Forest to the east (Binns 1996), with new records made for Wollemi NP. Several populations have also been recorded in Yengo NP during 2007 (pers. obs.). *Eucalyptus* sp. aff. *eugenioides* is an entity of uncertain taxonomic status, and further investigation is required.

EPBC Act: not listed; *TSC Act*: not listed; *IUCN (2001)*: DD (proposed); *ROTAP*: not listed; 3KC (proposed)

39. *Eucalyptus* sp. 'Howes Swamp Creek' (Doherty 26) (Myrtaceae)

Distribution within Wollemi – only known from Howes Swamp Creek along the Putty Road.

Habitat – Canopy layer of *Eucalyptus piperita, Angophora floribunda* and *Eucalyptus viminalis*, over a sparse understorey of *Acacia parramattensis, Bursaria spinosa, Pteridium esculentum, Persoonia oblongata, Lomatia silaifolia, Polyscias sambucifolia, Leucopogon muticus, Cryptandra amara, Platysace lanceolata, Imperata cylindrica var. major, Helichrysum scorpioides, Gonocarpus tetragynus,* and *Hypericum gramineum*.

Threats – frequent fire, over-collecting.

Conservation Status – although listed as threatened, the taxonomy of *Eucalyptus* sp. 'Howes Swamp Creek' [syn. *Eucalyptus wollemiensis* ms] is still uncertain, as the only known stand (of ~5 individuals) shows characteristics similar to *Eucalyptus angophoroides* (which occurs well to the south, in the Towrang district on the NSW South Coast and Tablelands). The remaining trees at Howes Swamp Creek are in poor health due to repeated burning, and it has been difficult to collect sufficient material to confirm the status of this taxon (K. Hill, National Herbarium, pers. comm.).

EPBC Act: **not listed;** *TSC Act*: **Endangered;** *IUCN (2001)*: **CR D1 (proposed);** *ROTAP*: **2ECi**

40. *Gonocarpus longifolius* (Schindler) Orch. (Haloragaceae)

Distribution within Wollemi – occurs across much of Wollemi NP, collections made in recent years suggest that this species is adequately conserved in this reserve.

Habitat – includes open forest dominated by *Corymbia maculata, Eucalyptus crebra* and *E. moluccana*, over an understorey of *Bursaria spinosa, Breynia oblongifolia, Exocarpus strictus, Sorghum leiocladum, Lomandra filiformis* subsp. *filiformis, Cymbopogon refractus, Eragrostis brownii* and *Dichondra repens* near Milbrodale in the north-east; open forest on shale soils supporting *Eucalyptus resinifera, E. globoidea, Syncarpia glomulifera, Allocasuarina torulosa* and *Angophora costata*, over *Persoonia linearis, Acacia implexa, Themeda australis, Aristida vagans, Anisopogon avenaceus, Entolasia stricta, Panicum simile, Imperata cylindrica* var. *major, Lomandra multiflora* subsp. *multiflora, Lomandra longifolia* and *Phyllanthus hirtellus* along the Drip Rock Trail in the south-east; and a riparian forest of *Casuarina cunninghamiana* subsp. *cunninghamiana* and *Angophora floribunda*, over *Tristaniopsis laurina, Leptospermum polygalifolium* subsp. *transmontanum, Backhousia myrtifolia, Hakea salicifolia, Ceratopetalum apetalum, Polyscias sambucifolia, Lomandra longifolia, Adiantum aethiopicum, Oplismenis imbecillis, Desmodium varians, Hydrocotyle laxiflora, Dichondra repens* and *Poa affinis* along Blackwater Creek in the north.

Threats – no threats identified.

Conservation Status – listed for Goulburn River, Blue Mountains, Border Ranges, and Mount Walsh NPs, with only Goulburn River NP

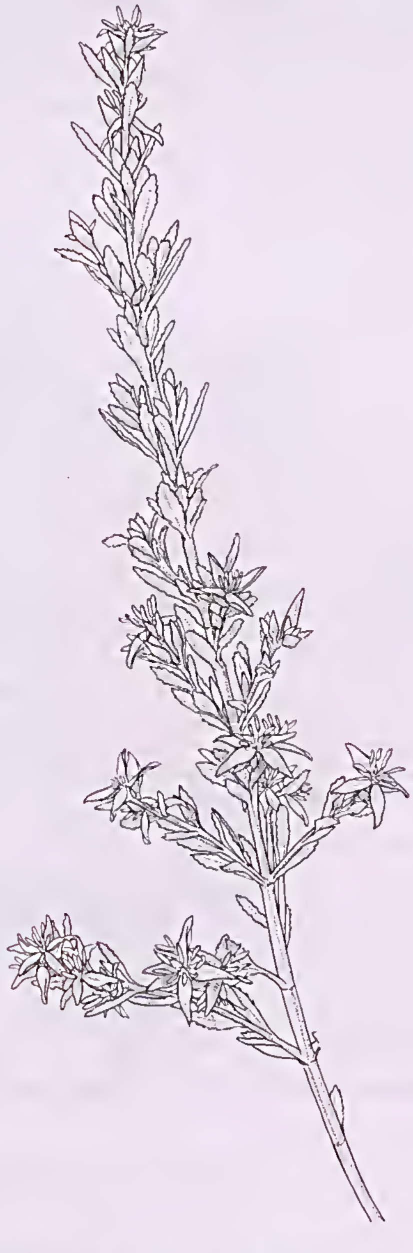

Fig. 15. *Haloragodendron gibsonii* (illustration by C. Wardrop 2005)

considered to support adequate populations (Briggs & Leigh 1996). Other populations have been recorded in Manobalai Nature Reserve (Peake & Bell in prep.), Gardens of Stone NP (Washington 2001a), Burragorang Valley (Fisher et al. 1995) and Gulguer Nature Reserve (James 1997). Bell (2001) suggested a revised code to 3RCa to reflect current knowledge.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RC-; 3RCa (Bell 2001)**

41. *Grevillea evansiana* (McKee) McGillivray (Proteaceae)

Distribution within Wollemi – principally around the Dunns Swamp (Kandos Weir) area in the central west, but also in outlying locations in the northern sections of the Newnes Plateau and around Glen Davis.

Habitat – occurs in a range of habitats including pagoda heath, open forest and hanging swamps. In pagoda heath at Dunns Swamp, associated species include *Leptospermum arachnoides, Calytrix tetragona, Leptospermum parvifolium, Leucopogon muticus, Leucopogon microphyllus* subsp. *pilibundus, Leptospermum sphaerocarpum, Prostanthera* sp. A., *Ochrosperma oligomerum. Dillwynia sericea, Callitris rhomboidea, Eucalyptus laophila* and *Laxmannia gracilis*. Above the pagoda heaths in an open forest of *Eucalyptus rossii, E. sparsifolia* and *E. punctata, Grevillea evansiana* occurs with an understorey of *Podolobium ilicifolium, Leptospermum sphaerocarpum, Leucopogon muticus, Monotoca scoparia, Leptospermum arachnoides, Kunzea ambigua, Brachyloma daphnoides* subsp. *daphnoides, Dillwynia phylicoides, Callitris endlicheri, Pomax umbellata, Lomandra glauca, Phyllanthus hirtellus, Rhytidosporum procumbens* and *Patersonia sericea*. In general terms, *Grevillea evansiana* is more common in the pagoda heaths of Dunns Swamp than the open forest habitat. In hanging swamp on the Newnes Plateau, *Grevillea evansiana* occurs with *Leptospermum squarrosum, Lepidosperma forsythii, Lepyrodia scariosa, Epacris obtusifolia, Sphaerolobium minus, Epacris microphylla* var. *microphylla, Almaleea incurvata, Dampiera stricta, Lycopodium laterale, Baumea rubiginosa, Boronia microphylla, Gleichenia dicarpa* and *Pultenaea canescens*. At Tea Tree Flat near Bogee, this species occurs in a non-pagoda heath of *Leptospermum arachnoides, Leptospermum parvifolium, Leucopogon muticus, Platysace lanceolata, Leucopogon microphyllus* subsp. *pilibundus, Calytrix tetragona, Leptospermum sphaerocarpum, Prostanthera saxicola* subsp. *bracteola, Acacia ulicifolia, Styphelia triflora, Acacia elongata* var. *elongata, Drosera auriculata, Lepidosperma viscidum, Amperea xiphoclada* var. *xiphoclada* and *Anisopogon avenaceus*. Near Box Hole Clearing, this species occurs in mallee heath of *Eucalyptus bensonii, E. multicaulis, E. laophila, Allocasuarina nana, Boronia floribunda, Kunzea ambigua, Allocasuarina distyla, Platysace lanceolata, Dillwynia acicularis, Banksia penicillata, Chloanthes stoechadis, Caustis pentandra, Actinotus minor, Dampiera stricta, Laxmannia gracilis* and *Acacia suaveolens*.

Threats – no threats identified.

Conservation Status – known only from Wollemi NP (Briggs & Leigh 1996). The range of habitats and the geographical spread of records suggest that at least 1000 plants are conserved; conservation risk code could be amended to 2VCa.

EPBC Act: **Vulnerable;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2VC-; 2VCa (proposed)**

42. *Grevillea johnsonii* McGillivray (Proteaceae) Johnson's Grevillea

Distribution within Wollemi – widespread across the northern portions of the park, extending down the western flank to at least Growee Gulf.

Habitat – typical habitat is heath or open woodland on the edges of rocky escarpments, but specimens have also been recorded below clifflines on steep slopes in open forest, and along drainage lines on deeper alluvial soils. Near Mt Oxford in the north-east of the park, associated species on an exposed upper slope include a canopy of *Eucalyptus sparsifolia, E. punctata, E. dwyeri* and *Corymbia trachyphloia* subsp. *amphistomatica*, over a sparse understorey of *Dodonaea viscosa* subsp. *cuneata, Boronia ledifolia, Pultenaea flexilis, Cassinia cunninghamii, Leptospermum trinervium, Acacia doratoxylon, Phebalium squamulosum* subsp. *gracile, Grevillea mucronulata, Maytenus silvestris, Cleistochloa rigida, Lomandra confertifolia* subsp. *rubiginosa, Lepidosperma gunnii, Lomandra glauca* and *Pomax umbellata*. At Cox's Gap in the north-west, *Grevillea johnsonii* occurs in an open forest of *Eucalyptus punctata, E. sparsifolia* and *E. fibrosa*, with an understorey of *Phebalium squamulosum* subsp. *gracile, Dodonaea triangularis, Hovea lanceolata, Pultenaea cunninghamii, Acacia penninervis, A. uncinata, Philotheca salsolifolia, Acacia crassa* subsp. *crassa, Leucopogon muticus, Cassinia cunninghamii, Cleistochloa rigida, Lomandra confertifolia* subsp. *rubiginosa, Lomandra glauca, Dianella revoluta* var. *revoluta, Goodenia rotundifolia, Joycea pallida* and *Hibbertia circumdens*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list only Goulburn River NP, where they consider populations to be inadequate. However, Bell (2001) has suggested that the conservation code for this species be amended to 2RCa, in view of populations recorded from reserves in the Goulburn River valley area over recent years. In addition populations are known from Manobalai NR (Peake & Bell in prep.) and at Mount Gundangaroo near Glen Davis (Benson & Keith 1990).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RCi; 2RCa (Bell 2001)**

43. *Grevillea montana* R.Br. (Proteaceae) Mountain Grevillea

Distribution within Wollemi – extensive populations in the Glen Gallic and Woodlands Trig areas of the northern sections of the park, as well as other populations along the Elcom Trail that runs south from Appletree Creek near Jerrys Plains.

Habitat – occurs predominantly in open forest of *Eucalyptus sparsifolia* and *E. punctata*, over an understorey of species such as *Pultenaea flexilis, Podolobium ilicifolium, Indigofera australis, Cleistochloa rigidia, Lomandra confertifolia* subsp. *rubiginosa, Pomax umbellata, Helichrysum adeonophorum* var. *waddelliae, Poranthera corymbosa, Hibbertia obtusifolia* and *Stypandra glauca*. In some locations, plants exceeding 2m in height are not uncommon, which is greater than reported in taxonomic texts.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list only Wollemi NP as supporting this species, although collections have also been made in Yengo and Werakata NPs (Bell 2004) and other relatively secure conservation tenures in the Hunter Valley over recent years (eg: Myambat Logistics Company site, Singleton Army Training Area). A revised conservation code of 2RCa has been previously suggested to better reflect the status of this species (Bell 2001).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2KC-; 2RCa (Bell 2001)**

44. *Grevillea obtusiflora subsp. obtusiflora* R.Br. (Proteaceae)

Distribution within Wollemi – DECCAtlas record from 2002 exists for this subspecies near Glen Alice in the south-west of the park. This population consists of several hundred plants, and extends over an area of 1.5km of Stacks Ridge and its side spurs in open eucalypt woodland on sandy soil (S. Clarke, pers. comm.).

Habitat – near Clandulla, populations occur in a woodland of *Eucalyptus crebra, E. dealbata* and *E. tenella*, over an understorey of species such as *Callistemon linearis, Acacia buxifolia, Acacia elongata, Leucopogon* sp., *Caustis flexuosa, Dionella sp, and Patersonia sp (NPWS 2001). McGillivray (1993) notes only that this taxon occurs in eucalypt woodland with a shrubby understorey, on loamy soils.*

Threats – vehicular access, inappropriate fire regimes and roadside management activities (NPWS 2001).

Conservation Status – NPWS (2001) noted that *G. obtusiflora* subsp. *obtusiflora* occurs in and adjacent to Clandulla State Forest near Rylstone to the west of the park, and that no populations were known from secure conservation lands.

EPBC Act: **not listed;** *TSC Act*: **Endangered;** *IUCN (2001)*: **VU D1+2 (proposed);** *ROTAP*: **2E**

45. *Gyrostemon thesioides* (Hook. f) A.S. George (Gyrostemonaceae)

Distribution within Wollemi – a single male plant recently discovered by Tony Rodd in the Colo River area (Bob Turner's Track) in the south-east of the park, but little information is available.

Habitat – reported habitat includes hillsides and riverbanks, with the Wollemi specimen found on an alluvial terrace above the normal flood zone.

Threats – site and habitat threatened by *Lantana camara* and other weeds.

Conservation Status – a fire-opportunist, *Gyrostemon thesioides* is reportedly confined to the Georges and Nepean Rivers in the wider Sydney region (Harden 1990c).

EPBC Act: **not listed;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN D1 (proposed);** *ROTAP*: **not listed; 2EC (proposed)**

46. *Haloragodendron gibsonii* Peter G. Wilson & M. Moody (Haloragaceae)

Distribution within Wollemi – recorded from the Wollangambe Wilderness in the south of the park, and on the Newnes Plateau. At least seven populations are known.

Habitat – Fairley (2004) notes (in discussion on *Haloragodendron lucasii*) the general habitat of the Wollemi populations as being in rugged and remote gorges of Bungleboori and Yarramun Creeks in the Wollangambe Wilderness. Wilson and Moody (2006) describe habitat as sheltered gullies and on creek banks, in open forest of *Eucalyptus oreades* with *Ceratopetalum apetalum*, *Logania albiflora*, *Todea barbara*, *Gahnia* sp. and *Prostanthera* sp.. In more exposed sites (such as dissected cliff-lines and pagodas), plants have been found in heath associated with species such as *Allocasuarina distyla*, *Banksia ericifolia*, *Banksia conferta*, *Eucalyptus stricta*, *Leptospermum trinervium*, *Acacia hamiltoniana*, *Olax stricta* and *Caustis pentandra*.

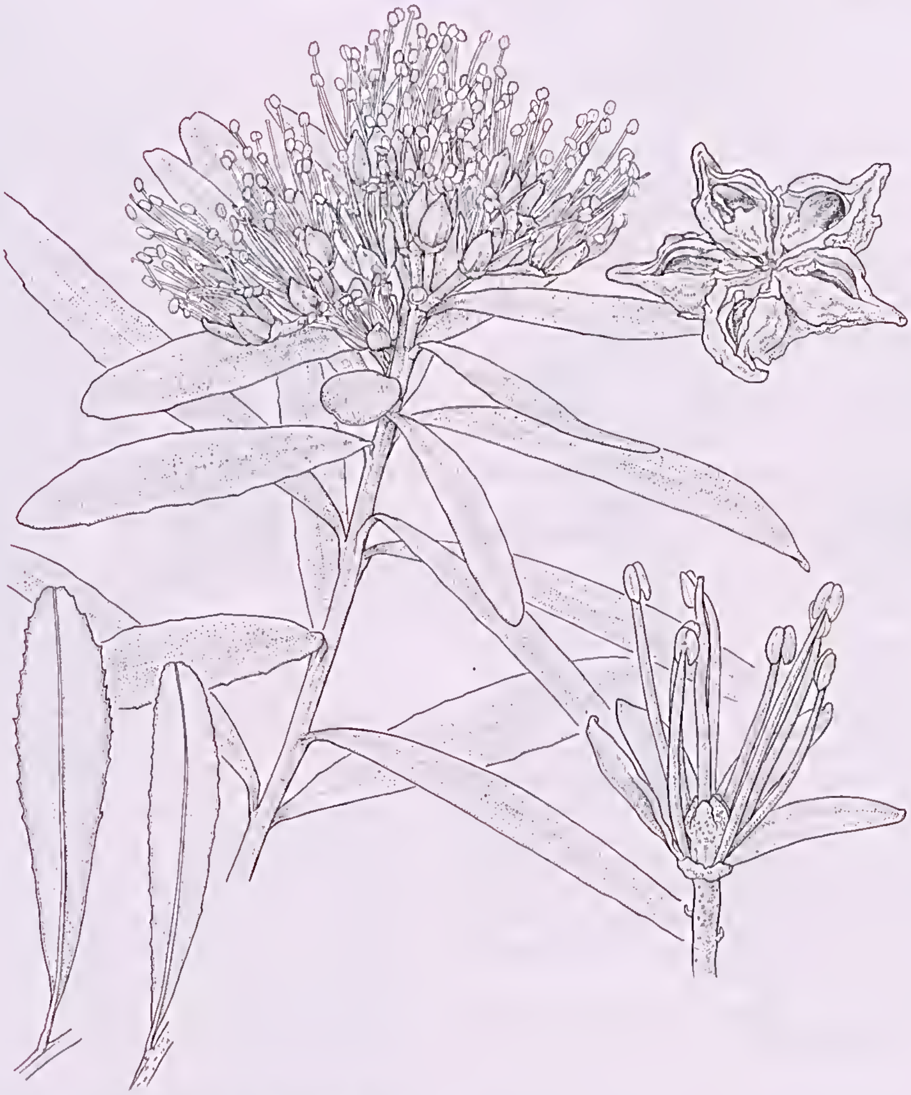

Fig. 16. *Leionema scopulinum* (illustration by C. Wardrop 2004)

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) coded this species 2Rcat (as *Haloragodendron lucasii* subsp. 1 Wollangambe Creek). Orchard (1990) outlines the rediscovery of this species and the closely-related *Haloragodendron lucasii*.

EPBC Act: **Endangered;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN D1 (proposed);** *ROTAP*: **2RCat**

47. *Homoranthus cernuus* (R.Baker) Craven & S.R.Jones (Myrtaceae)

Distribution within Wollemi – several populations have been recorded in the Growee Gulf area in the west of the park. These observations would concur with the adequate reservation status applied to this species by Briggs and Leigh (1996).

Habitat – near Oz Mountain and in the upper catchment of Long Creek, *Homoranthus cernuus* occurs in dry open forest of *Eucalyptus sparsifolia* and *E. punctata*, over an understorey of *Allocasuarina littoralis, Dillwynia floribunda* var. *teretifolia, Philotheca salsoloides, Gompholobium virgata subsp. aspalathoides, Doodenia decurrens, Dampiera lanceolata, Gonocarpus elatius, Lomandra confertifolia* subsp. *rubiginosa, Lomandra glauca* and *Cleistochloa rigida*. In the middle Lee Creek catchment, habitat includes heath on pagoda rock formations, associated with *Allocasuarina gymnanthera, Leptospermum parvifolium, Dillwynia sericea, Philotheca salsolifolia, Leptospermum sphaerocarpum, Baeckea densifolia, Leptospermum arachnoides, Caustis pentandra, Leucopogon muticus, Isopogon dawsonii* and other rare species such as *Banksia penicillata, Prostanthera hindii* and *Pentachondra dehiscens*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) note this species as occurring only in Wollemi NP.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RCa**

48. *Isotropis foliosa* Crisp (Fabaceae: Faboideaea)

Distribution within Wollemi – about 100 plants recorded in the Apple Tree Creek area, near Denman, northern Wollemi during the 1990s, in dry, rocky, sandy soils in very open vegetation (T. Tame, pers comm.).

Habitat – on alluvial soils supporting open grassy forest of *Eucalyptus crebra* (Fallding et al. 1997). This habitat is widespread across the northern sections of Wollemi, and additional unrecorded populations may be present.

Threats – grazing from adjacent properties.

Conservation Status – *Isotropis foliosa* is a poorly known species occupying an extensive range between the Moreton district of Queensland, south to the Hunter Valley. Within the Hunter Valley, populations are known from the Myambat Logistics Company site near Denman just outside of Wollemi (Fallding et al. 1997), on the boundary of Wingen Maid Nature Reserve (Hill et al. 2001), and at three other locations near Scone (T. Peake, pers. comm.). A small population occurs at Derra Derra Ridge on the North Western Slopes (Benson et al. 1996). Crisp (1987) suggested a conservation risk code of 2E when describing *Isotropis foliosa*, although at that time it was known only from Queensland. Subsequent populations discovered in NSW resulted in the revised code of 3KC- by Briggs and Leigh (1996), although a Vulnerable listing may now be more appropriate.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **3VC- (proposed)**

49. *Kennedia retrorsa* Hemsley (Fabaceae: Faboideae)

Distribution within Wollemi – recorded from Hungerford Creek catchment in the east of the park (1969), near Bilpin in the south (1969), and Dingo Creek and the Baerami Valley (1984, 1999) in the north (DECC Atlas Gibson 2002). Gibson (2002) discusses a fruitless search in the Hungerford Creek location, and suggests there may have been identification and/or databasing errors with the original collection.

Habitat – Maryott-Brown and Wilks (1993) indicate that *Kennedia retrorsa* occurs in sheltered forests on rich soils, in association with *Eucalyptus deanei, Smilax australis, Rapanea howittiana, Baeckea cunninghamii* and *Senecio* spp.

Threats – no threats identified.

Conservation Status – Goulburn River (inadequately conserved) and Wollemi (adequate) NPs (Briggs & Leigh 1996). Due to lack of recent records, there may be a case for upgrading the risk code to 2VCi

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **2VCa; 2VCi (proposed)**

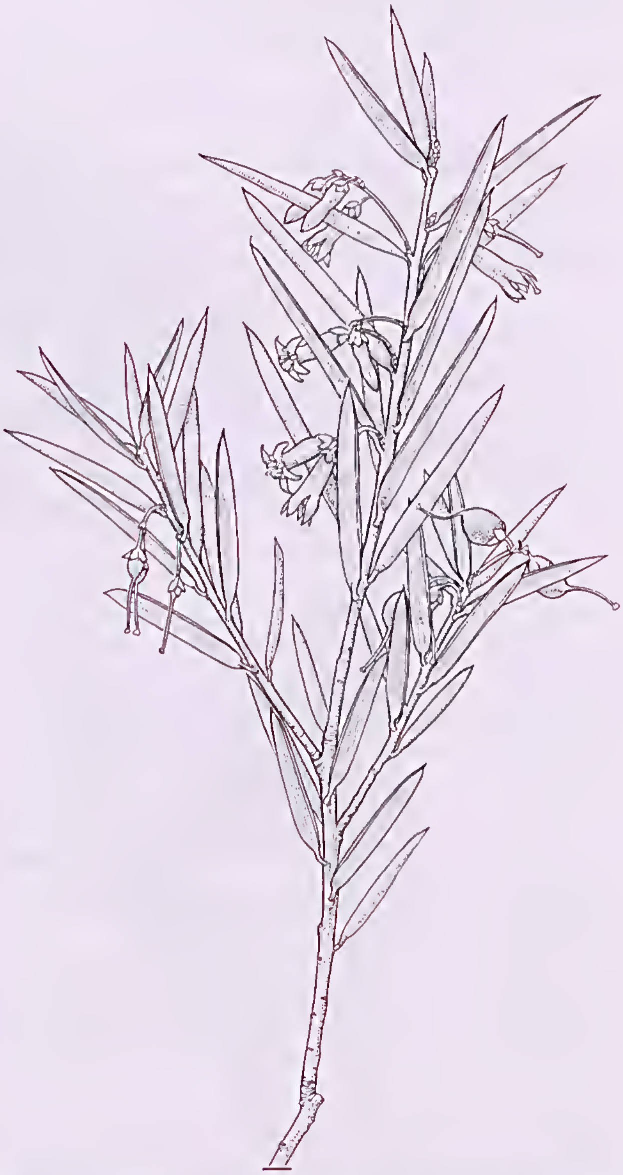

Fig. 17. *Lissanthe sapida* (illustration by C. Wardrop 2003)

50. *Keraudrenia corollata* var. *denticulata* C.White (Sterculiaceae)

Distribution within Wollemi – recorded in the proposed Morans Rocks additions adjacent to the south-eastern corner of the park (Latham 1995).

Habitat – Sydney ridge-top woodland on Hawkesbury Sandstone (Latham 1995). Benson and McDougall (2001) described habitat for this species as open forest with *Eucalyptus deanei, Tristaniopsis laurina, Backhousia myrtifolia, Commersonia fraseri, Rulingia dasyphylla* and *Hibiscus heterophyllus.*

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list this species only for Gibraltar Range NP near Grafton, with no reservation in the Greater Sydney area.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **3RC**

51. *Leionema lamprophyllum* subsp. *orbiculare* F.M. Anderson (Rutaceae)

Distribution within Wollemi – within and near Wollemi NP in the vicinity of Dunns Swamp (Kandos Weir), also from Newnes and Coricudgy State Forests

Habitat – restricted to the exposed sandstone turrets and domes that characterise sections of the west of Wollemi, commonly referred to as "pagodas". Anderson (1999) notes that the subspecies has been recorded from open heath to open shrubland of *Acacia* and *Calytrix* species, to low open *Eucalyptus*-dominated woodland. Benson and McDougall (2001) add the associates *Banksia ericifolia, Banksia spinulosa, Calytrix tetragona* and *Brachyloma daphnoides*. Such habitat is reasonably common in restricted areas along the western escarpment of Wollemi, and consequently there is considerable potential habitat for this taxa.

Threats – no threats identified.

Conservation Status – Anderson (1999) described three new subspecies of *Leionema lamprophyllum* (formerly *Phebalium lamprophyllum*), with subsp. *orbiculare* occuring on the western escarpment including Wollemi NP, and applied a conservation risk code of 2R-. A small population of this subspecies recorded in rocky cliffline habitat in Pokolbin State Forest, over 100 km to the east, is now listed as an Endangered Population in the Hunter Catchment, on the NSW *TSC Act 1995* (T. Tame, pers. comm.).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **2R- (Anderson 1999)**

52. *Leionema scopulinum* B.M. Horton & Crayn (Rutaceae)

Distribution within Wollemi – known from 29 occurences in the north-west of the park, in the headwaters of Lee Creek and the Growee River (Horton et al. 2004). A total population of about 1500 plants within an area 14 km by 7 km has been estimated.

Habitat – Habitat is described as heathland on shallow sandy soils on Narrabeen Sandstone pagodas, where common associated species include *Acacia obtusifolia, A. terminalis, A. ulicifolia, Allocasuarina distyla, Amperea xiphoclada, Banksia penicillata, Boronia anemonifolia, B. angustisepala, Callitris endlicheri, Calytrix tetragona, Caustis pentandra, Coopernookia barbata, Dampiera adpressa, Dillwynia retorta, Eucalyptus rossii, Epacris coriacea, E. reclinata, Exocarpus cupressiformis, Goodenia decurrens, Hibbertia monogyna, Homoranthus cernuus, Isopogon anemonifolius, Leptospermum arachnoides, L. parvifolium, L. sphaerocarpum, Leucopogon muticus, L. setiger, Logania albiflora, Monotoca scoparia, Ochrosperma oligomerum, Persoonia linearis, Phebalium squamulosum* subsp. *gracile, Philotheca salsolifolia* subsp. *salsolifolia*, *Platysace linifolia, Prostanthera hindii* and *Pseudanthus pimeleoides* (Horton et al. 2004; Washington 2004).

Threats – no threats identified.

Conservation Status – Horton et al. (2004) suggest that listing under the NSW *TSC Act 1995* as Vulnerable or Endangered may be appropriate, and a provisional conservation risk code of 2RCit.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2RCit (Horton et al. 2004)**

53. *Leionema sympetalum* (Paul G. Wilson) Paul G. Wilson (Rutaceae) Rylstone Bell

Distribution within Wollemi – Populations are known from approximately 1.5kms south of Dunns Swamp (Kandos Weir); at the headwaters of Coorongooba Creek to the west of the Army Road; on the slopes of Mt Iris in the west; north of Tayan Peak; and in the Capertee River area 5km north-west of Glen Davis (DECC Atlas; S. Clarke, pers. comm.).

Habitat – Benson and McDougall (2001) indicate rocky outcrops with woodland of *Eucalyptus laophila* and *Eucalyptus bensonii*, and heath

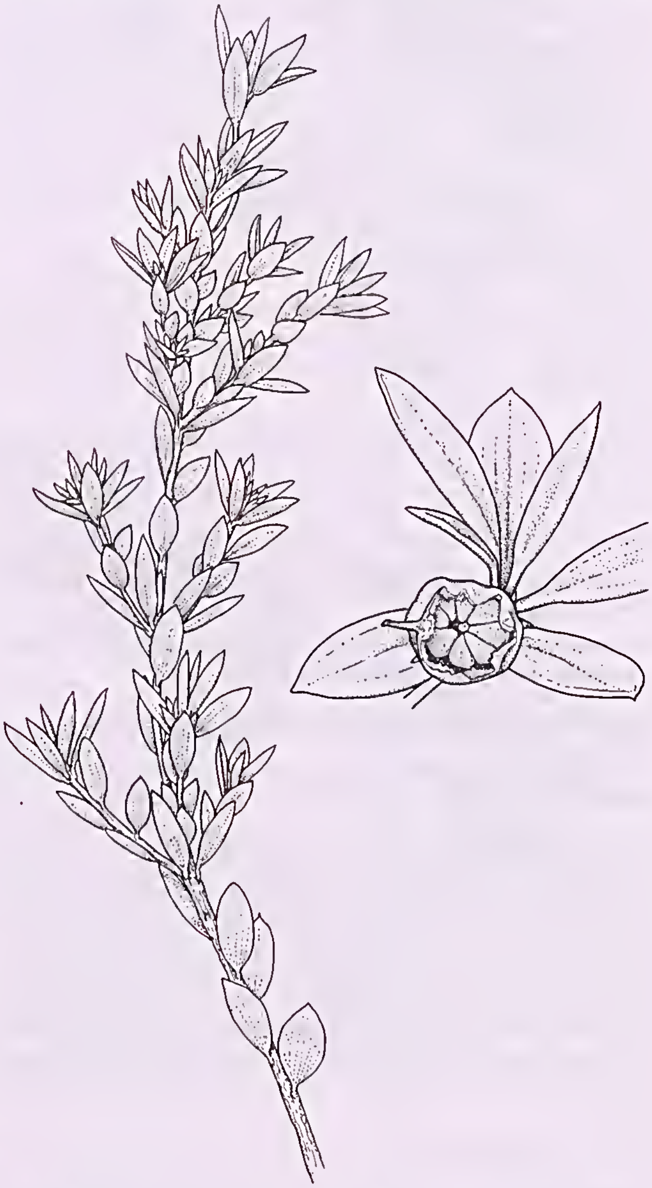

Fig. 18. *Pentachondra dehiscens* (illustration by Lesley Elkan 2000)

of *Allocasuarina distyla, Caustis pentandra* and *Acacia suaveolens* as habitat. In some populations, plants support 4- or 5-flowered inflorescences rather than the reported 1–3, and regenerate from the rootstock following severe fire (S. Clarke, pers. comm.)

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) only list Wollemi NP

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **NT (proposed);** *ROTAP*: **2VC-**

54. *Leionema* sp. 'Colo River' (Weston 2423) (Rutaceae)

Distribution within Wollemi – undescribed species (Weston & Harden 2002) known only from riparian forests along the Colo River and Hungryway Creek.

Habitat – Benson and McDougall (2001) note *Leionema* sp. 'Hungryway Creek' as a poorly-known local endemic occuring within Wollemi NP. Associated species are *Tristaniopsis laurina, Stenocarpus salignus, Lomatia myricoides* and *Backhousia myrtifolia*.

Threats – no threats identified.

Conservation Status – In a review of the former *Phebalium*, Wilson (1998b) suggested that specimens from this location, formerly known as *Phebalium* sp. A, may be hybrids with *Leionema elatius* due to the presence of deformed flowers and apparently sterile anthers. However, *Leionema elatius* has not been recorded from the Colo River area, and further sampling is required.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **2VC- (Wilson 1998b)**

55. *Leptospermum spectabile* J.Thompson (Myrtaceae)

Distribution within Wollemi – occurs only along the Colo River in the south-eastern portion of Wollemi, where it grows on rocky sandstone banks amongst sandstone boulders (Thompson 1989; Thompson & Logan 2002).

Habitat – occurs in localised small populations in sandy alluvium and amongst rocky boulders in areas subject to flooding, within thickets of *Tristaniopsis laurina* and *Lomatia myricoides* (Benson 1990).

Threats – no threats identified.

Conservation Status – coded 2RC-, and only conserved in Wollemi NP (Briggs & Leigh1996)

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D1+2 (proposed);** *ROTAP*: **2RC-; 2RCt (proposed)**

56. *Leucochrysum graminifolium* Paul G. Wilson (Asteraceae)

Distribution within Wollemi – Rocky Creek and Mt Dawson areas in the south-west, north of Newnes Plateau.

Habitat – In the Rocky Creek area of the Newnes Plateau, *Leucochrysum graminifolium* occurs in rocky pagoda heath with *Banksia ericifolia, Allocasuarina nana, Dillwynia floribunda* var. *teretifolia, Prostanthera hindii, Leptospermum parvifolium, Calytrix tetragona, Cryptandra propinqua, Petrophile pulchella, Leptospermum arachnoides, Acacia hamiltoniana, Schoenus ericetorum, Dampiera stricta, Stylidium lineare, Hakea laevipes* and *Hakea propinqua*. A few scattered plants were noted at this location, and it is possible that most pagodas in this area support the species. Plants are also known from the Red Rocks and Mt Dawson areas of the park near Newnes (H. Washington, pers. comm.).

Threats – no threats identified.

Conservation Status – listed by Briggs and Leigh (1996) with a conservation code of 2R. Apart from Wollemi, there is one 1993 record from the nearby Pantoneys Crown Nature Reserve (DECCAtlas), and Washington (2001a) has also recorded this species within the adjacent Gardens of Stone NP, where it is common on rocky pagodas and rock shelves. These recent records represent the first for a conservation reserve, and consequently it is suggested that the conservation risk code be amended to 2RC-.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2R; 2RC- (proposed)**

57. *Lissanthe sapida* R.Br. (Epacridaceae)

Distribution within Wollemi – principally occurs in the southern portions around Mountain Lagoon and the Colo River, although Maryott-Brown and Wilks (1993) indicate some small populations in the Mt Popong area towards the north-east of the park.

Habitat – Maryott-Brown and Wilks (1993) summarise the habitat of this species as dry sheltered forest on a variety of sandstone and mudstone derived soils, in association with *Eucalyptus punctata, E. globoidea, Pultenaea cunninghamii, Dodonaea triquetra, Podolobium ilicifolium, Phyllanthus hirtellus* and various *Lomandra* species. Along the Culoul Range in south-eastern Wollemi, *Lissanthe sapida* occurs in an open forest of *Corymbia eximia, Eucalyptus sparsifolia* and *E. piperita*, over an understorey of *Dillwynia floribunda* var. *teretifolia, Leptospermum trinervium, Dillwynia acicularis, Boronia ledifolia, Persoonia linearis, Platysace linearifolia, Grevillea buxifolia* subsp. *buxifolia, Stylidium productum, Hibbertia obtusifolia, Lomandra glauca* and *Patersonia glabrata*. Other habitats in southern Wollemi include sheltered forest of *Allocasuarina torulosa, Corymbia gummifera, Syncarpia glomulifera, Angophora costata* and *Eucalyptus sparsifolia*, over an understorey of *Lomatia silaifolia, Kunzea ambigua, Podolobium ilicifolium, Xylomelum pyriforme, Tetratheca thymifolia, Goodenia decurrens, Entolasia stricta, Stylidium productum* and *Dianella caerulea*; and an exposed woodland of *Eucalyptus piperita, Angophora costata, Corymbia gummifera, Eucalyptus sparsifolia, Banksia serrata, Dillwynia retorta, Gompholobium latifolium, Leptospermum polyanthum, Pteridium esculentum, Leucopogon muticus, Lomandra filiformis* subsp. *filiformis, Amperea xiphoclada* var. *xiphoclada, Lomandra glauca* and *Stylidium productum*.

Threats – no threats identified.

Conservation Status – present in Blue Mountains, Wollemi and Dharug NPs (Briggs & Leigh 1996). Maryott-Brown and Wilks (1993) note that this species occurs on the western border of Yengo NP, and James (1997) notes the species for Gulguer Nature Reserve. NPWS (2003b) indicate that it is well represented within the Warragamba Special Area, which includes several conservation reserves.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RCa**

58. *Lomandra fluviatilis* (R.Br.) A.T.Lee (Lomandraceae)

Distribution within Wollemi – recorded from the Colo River, Howes Valley and northen parts of the park (Maryott-Brown and Wilks 1993; Fairley 2004).

Habitat – Maryott-Brown and Wilks (1993) indicate that this species occurs in moist sheltered areas in creek beds, growing amongst sandstone outcroppings.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) note this species for Blue Mountains, Morton, Garigal, Marramarra, and Royal NPs, and Bents Basin State Recreation Area (Briggs & Leigh 1996). It is also known from Heathcote NP (pers obs.), Gulguer Nature Reserve (James 1997) and Gardens of Stone NP (Washington 2001a).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RCa**

59. *Macrozamia elegans* K.D. Hill & D.L. Jones (Zamiaceae)

Distribution within Wollemi – Mountain Lagoon, Cedar Ridge and Grassy Hill between the Colo River and the Putty Road (Hill 1998; Fairley 2004).

Habitat – dry sclerophyll woodland on undulating to steeply sloping sites on sandstone.

Threats – illegal collecting of seeds and plants

Conservation Status – Hill (1998) suggests that this species is potentially under threat from habitat destruction and poaching, despite much of the known population lying within NP. Donaldson (2003) lists this species with an IUCN code of EN A2ad.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **EN A2ad (Donaldson 2003);** *ROTAP*: **2VC-**

60. *Melaleuca deanei* F. Muell. (Myrtaceae) Deane's Honey-Myrtle

Distribution within Wollemi – a single DECCAtlas record from 1998 near Upper Colo in the south-east of the park, however further details are unavailable.

Habitat – Fairley (2004) indicates that this species prefers dry ridges with sandy soils, or with laterite in shrubby woodland, while Maryott-Brown and Wilks (1993) suggest wet heaths near streams or perched swamps on ridges of Hawkesbury Sandstone geology.

Threats – no threats identified.

Conservation Status – represented within several coastal reserves, including Brisbane Water, Garigal, Heathcote, Ku-ring-gai Chase, Royal and Morton NPs (Briggs & Leigh 1996).

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU C2(ai) (proposed);** *ROTAP*: **3RC-**

61. *Melaleuca groveana* Cheel & C. White (Myrtaceae) Grove's Paperbark

Distribution within Wollemi – known from one location on the California Trail in the north-east of the park, although likely to be scattered elsewhere in the north-east.

Habitat – on the California Trail, *Melaleuca groveana* occurs in an open forest of *Eucalyptus fibrosa, E. sparsifolia, E. punctata* and *Angophora costata* over a shrubby understorey of *Acacia linifolia, Pultenaea scabra, Pultenaea flexilis,* and *Lasiopetalum ferrugineum* var. *cordatum,* and a ground layer of *Entolasia stricta, Cleistochloa rigida, Anisopogon avenaceus, Austrostipa scabra* subsp. *falcata, Lomandra filiformis* subsp. *coriacea,* and *Phyllanthus hirtellus.* Individual specimens of *Melaleuca groveana* were noted to be 5–8m in height, and several were resprouting from their bases following fire. It is likely that up to 50 plants occur at this location. Populations present in the adjacent Yengo NP occur in close proximity to rocky outcrops, but still within an open forest or woodland of *Eucalyptus punctata, E. sparsifolia* and *E. crebra* (Maryott-Brown & Wilks 1993).

Threats – no threats identified.

Conservation Status – Populations are known from Yengo NP (Bell et al. 1993, where they are considered inadequate) as well as Tomaree NP (Benson 1981; Bell 1997b, inadequate) and Six Brothers Flora Reserve (inadequate, Briggs & Leigh 1996). Binns (1996) also reports the species from Pokolbin and Corrabare State Forests. In Queensland, this species also occurs in Blacktown Tableland and Mount French NPs (unknown population sizes), and Beerwah NP (inadequate) (Briggs & Leigh 1996).

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU C2(ai); D2 (proposed);** *ROTAP*: **3RC-**

62. *Olearia cordata* Lander (Asteraceae)

Distribution within Wollemi – recorded at two locations above Milbrodale Creek in the north-eastern section of the park (Bell 1998), extending its known range north from Wollombi (Lander 1992). Other known populations include the ridges around the Colo and Capertee Rivers, and the Mountain Lagoon area in the south (DECC Atlas; Fairley 2004).

Habitat – above Milbrodale Creek, scattered plants were recorded on a ridgeline in an open forest of *Eucalyptus sparsifolia, E. beyeriana, E. fibrosa,* and *Angophora costata.* Understorey vegetation included

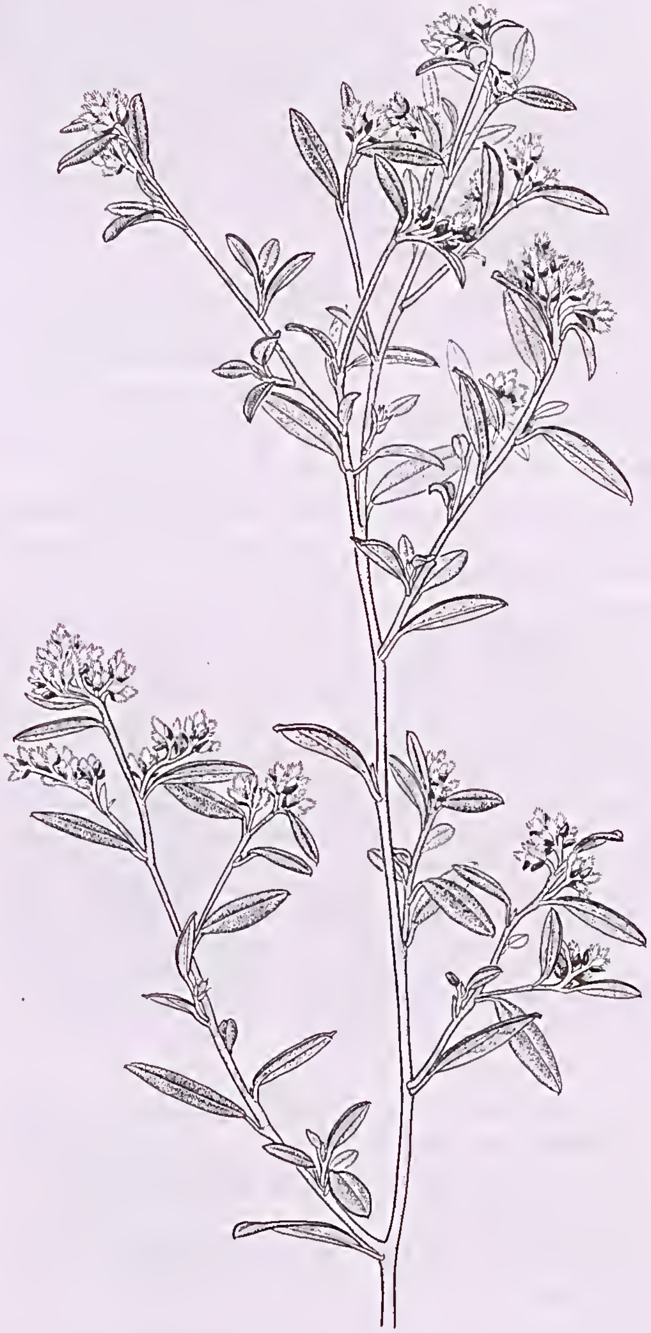

Fig. 19. *Pomaderris sericea* (illustration by Lesley Elkan 2004)

the shrubs *Monotoca scoparia, Acacia linifolia, Pultenaea scabra, Acacia terminalis, Exocarpus strictus, Acacia saliciformis, Podolobium ilicifolium*, and *Acacia ulicifolia*, and the herbs/ grasses *Lomandra obliqua, Entolasia stricta, Patersonia sericea, Lomandra filiformis* subsp. *coriacea, Goodenia heterophylla, Anisopogon avenaceus, Dianella revoluta* var. *revoluta* and *Panicum simile*. Further down the ridge in a lower slope position, associated species included *Eucalyptus punctata, E. beyeriana, E. sparsifolia* and *Angophora euryphylla* in the canopy, with the shrubs *Prostanthera violacea, Dodonaea triquetra, Pultenaea scabra, Gompholobium virgatum* var. *aspalathoides, Grevillea mucronulata, Podolobium ilicifolium, Bursaria spinosa*, and the herbs/ grasses *Pomax umbellata, Phyllanthus hirtellus, Lomandra filiformis* subsp. *coriacea, Entolasia stricta, Dianella caerulea* var. *caerulea, Actinotus helianthi*, and *Aristida vagans*. Both areas had suffered an intense fire three years previously, which had dramatically opened up the understorey vegetation. Estimates of around 80–100 plants were made at these locations, although not all areas were examined thoroughly. Maryott-Brown and Wilks (1993) report that populations of *Olearia cordata* in the adjacent Yengo NP occur in a habitat comprising *Angophora costata, Angophora bakeri, Eucalyptus punctata* and *Corymbia eximia* in the canopy, over a shrub layer of *Allocasuarina torulosa, Acacia linifolia, Persoonia linearis, Leucopogon muticus* and various grasses.

Threats – frequent fire events.

Conservation Status – These authors list this species for Wollemi and Yengo NPs, as well as Wisemans Ferry Historic Site. All three reserves reportedly support inadequate populations (Briggs & Leigh 1996).

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU B1; C2b (proposed);** *ROTAP*: **2VCi**

63. *Olearia quercifolia* Sieber ex DC (Asteraceae)

Distribution within Wollemi – a DECC Atlas record from 2004 exists for *Olearia quercifolia* from the Galah Mountain area in the south-west of the park, along the Mt Cameron Fire Trail.

Habitat – The NSW Scientific Committee (2005) include this species in Newnes Plateau Shrub Swamp Endangered Ecological Community, listed under the NSW TSC Act 1995. This community is dominated by shrubs, with a variable cover of sedges. Shrubs have a dense to open cover, and include *Baeckea linifolia, Grevillea acanthifolia* subsp. *acanthifolia, Epacris paludosa* and *Leptospermum* species. The cover of sedges varies inversely with shrub cover. Common sedges include *Baloskion australe, Empodisma minus, Lepyrodia scariosa* and *Lepidosperma limicola*, while herbs include *Patersonia fragilis* and *Xanthosia dissecta*. *Gleichenia dicarpa* and *Gymnoschoenus sphaerocephalus* may occur around drainage lines, while *Lomandra longifolia* may be prominent around the swamp margins. Douglas and Bell (in prep.) note that *Olearia quercifolia* occurs in plateau swamps in the Blue Mountains, which include a fern-dominated form, sedge-dominated form, and a *Leptospermum* and *Hakea*-dominated form, all of which can occur in a single swamp.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) note this species for Blue Mountains and Kosciusko NPs.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RC-**

64. *Ozothamnus tesselatus* (Maiden & R.Baker) A.Anderb. (Asteraceae)

Distribution within Wollemi – restricted to the drier, northern footslopes of Wollemi, such as around Coxs Gap and the major valleys draining into the Goulburn River, generally along the talus slopes at the edge of the escarpment.

Habitat – scattered populations of this species occur in open woodland or forest on Permian Sediments dominated by *Eucalyptus dawsonii, E. punctata* and *E. albens/ moluccana*, with an understorey of species such as *Acacia ixiophylla, Dodonaea viscosa, Bursaria longissima, Lomandra multiflora* subsp. *multiflora, Opercularia hispida, Dianella revoluta, Lomandra confertifolia* subsp. *rubiginosa* and *Sida corrugata*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) indicated that Wollemi and Goulburn River NPs support the only known populations of this species from gazetted reserves. McRae and Cooper (1985), Bell (1997c) and Hill (1999) detail populations in Goulburn River NP.

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU B1 (proposed);** *ROTAP*: **2VC-**

65. *Pentachondra dehiscens* W. Cherry (Ericaceae)

Distribution within Wollemi – growing on cliff faces in the rugged west of the park, with few populations known. Recently described (Cherry et al. 2001), based on specimens collected from the Oz Mountain area of Wollemi and the Grose River valley in Blue Mountains NP.

Habitat – restricted to crevices in sandstone outcrops and cliff lines, usually with a south to south-western aspect, in sheltered to open situations in eucalypt woodlands and forests. Associated species include *Rupicola ciliata, Dracophyllum secundum, Epacris muelleri, Epacris crassifolia* and *Epacris reclinata*.

Threats – no threats identified.

Conservation Status – Cherry et al. (2001) suggest a conservation risk code of 3RC.

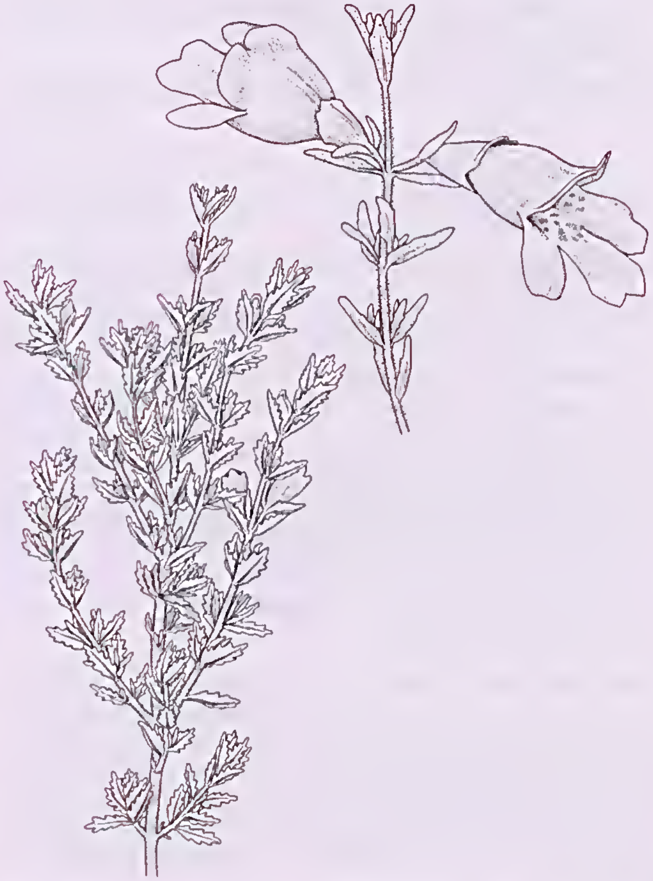

Fig. 20. *Prostanthera cryptandroides* (illustration by Lesley Elkan 1998)

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **3RC (Cherry et al. 2001)**

66. *Persoonia hirsuta* subsp. *evoluta* L.A.S. Johnson & P.H. Weston (Proteaceae)

Distribution within Wollemi – recorded around the Putty district in the central east of the park, extending west to near Glen Davis, and occuring as scattered individuals or in small groups (Weston 2002).

Habitat – mountainous areas between Putty and Glen Davis (Fairley 2004). No other habitat information available.

Threats – no threats identified.

Conservation Status – two subspecies of *Persoonia hirsuta* are currently recognised, both of which intergrade extensively from the lower Blue Mountains to within 15km of the coast. *Persoonia hirsuta* subsp. *hirsuta* has linear to narrow-oblong leaves 0.75–1.5mm wide, with revolute margins, and occurs from Gosford to Royal NP; *Persoonia hirsuta* subsp. *evoluta* shows spathulate to elliptic or narrowly-elliptic leaves 1.5–5mm wide, with recurved margins, and occurs from the Putty district to Glen Davis and Hill Top (Weston 2002). Briggs and Leigh (1996) include Blue Mountains, Wollemi, Dharug, Ku-ring-gai Chase, Marramarra, Royal, and Sydney Harbour NPs as reserves supporting this species, stating all but Wollemi NP carry inadequate populations.

EPBC Act: **Endangered;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN B1 (proposed);** *ROTAP*: **3KCi**

67. *Persoonia marginata* A. Cunn. Ex R.Br. (Proteaceae) Clandulla Geebung

Distribution within Wollemi – a single DECC Atlas record from 1999 for the northern rim of Wollemi, in the Dingo Creek area. Requires confirmation as all other records occur south of Rylstone on older sediments (DEC 2000).

Habitat – occurs in sclerophyll forest on sandstone, in woodland of *Eucalyptus punctata, E.sparsifolia, E. rossii, E. fibrosa* and *E.crebra*. Associated understorey species include *Acacia buxifolia, Exocarpos strictus, Acacia terminalis, Pultenaea microphylla, Acacia verniciflua, Dillwynia phylicoides, Platysace ericoides, Persoonia linearis* and *Grevillea ramosissima*. Ground layer species include *Joycea pallida, Lomandra filiformis* var. *coriacea, Dianella revoluta* and *Chrysocephalum apiculatum* (DEC 2000).

Threats – no threats identified.

Conservation Status – principally occurs within the Clandulla State Forest near Kandos (NPWS 2000c), but is also present in Gardens of Stone NP to the south-west of Wollemi (Washington 2001a).

EPBC Act: **Vulnerable;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **EN B1 (proposed);** *ROTAP*: **2V**

68. *Philotheca obovalis* (Cunn.) Paul G. Wilson (Rutaceae)

Distribution within Wollemi – recorded on the northern Newnes Plateau, and east along Mt Cameron Fire Trail.

Habitat – In the area north of Newnes Plateau, *Philotheca obovalis* occurs in montane rocky heath, associated with species such as *Banksia ericifolia, Leptospermum parvifolium, Eucalyptus laophila, Dillwynia floribunda var. teretifolia, Leptospermum arachnoides, Calytrix tetragona, Platysace lanceolata, Kunzea ambigua, Baeckea densifolia, Lomandra glauca, Schoenus turbinatus, Allocasuarina nana* and *Grevillea sericea*. Along the Mt Cameron Fire Trail, it occurs in an open forest of *Eucalyptus sclerophylla, E. piperita* and *E. sieberi*, over an understorey of several sclerophyllous species including *Dillwynia phylicoides, Hakea propinqua, Hakea dactyloides, Hibbertia serpyllifolia, Leptospermum sphaerocarpum, Telopea speciosissima, Banksia serrata, Phyllota squarrosa, Petrophile pulchella, Podolobium ilicifolium, Caustis flexuosa, Lomandra obliqua* and *Patersonia glabrata*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) considered that this species is adequately conserved in Blue Mountains NP, with insufficient information available on population sizes within Wollemi NP. Washington (2001a) also records it near Mt Jamison and Point Cameron in Gardens of Stone NP.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RCa (as *Eriostemon obovalis*)**

69. *Pimelea curviflora* var. *curviflora* R. Br. (Thymelaeaceae)

Distribution within Wollemi – Latham (1995) includes this taxon for the proposed Morans Rock addition to Wollemi near Maroota in the south-east, but no other records are known.

Habitat – Sydney ridge-top woodland on Hawkesbury Sandstone geology (Latham 1995). Benson and McDougall (2001) describe habitat for this species as woodland on ridges and upper slopes, supporting *Corymbia eximia, Eucalyptus capitellata, E. sieberi* and *E. punctata*, and open forest of *E. pilularis, Angophora costata, Corymbia gummifera* and *Eucalyptus sieberi*. Such habitat is widespread in the south-eastern sections of the park, and there is potential for other populations to be present.

Threats – no threats identified.

Conservation Status – restricted to coastal areas around Sydney (Harden 1990a). In listing the species, the NSW Scientific Committee noted that this taxon is known only from one locality in each of Garigal NP and

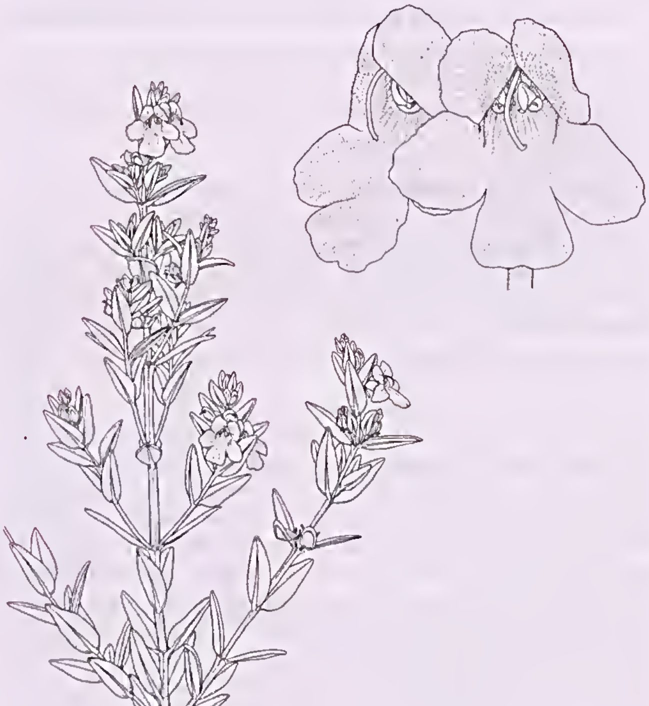

Fig. 21. *Prostanthera hindii* (illustration by Lesley Elkan 1997)

Muogamarra Nature Reserve, and that a total of only 20 populations were known from North Sydney to Maroota. Benson and McDougall (2001) also note its presence in Ku-ring-gai Chase and Wollemi NPs.

EPBC Act: **Vulnerable;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **EN B1 (proposed);** *ROTAP*: **2VC- (proposed)**

70. *Platysace clelandii* (Maiden & Betche) L.Johnson (Apiaceae)

Distribution within Wollemi – recorded in the hills around the Colo and Capertee Rivers in the south, east of Glen Davis in the west, and near the Kekeelbon Mountains in the centre of the park. Latham (1995) notes the species as occuring in the proposed Morans Rock addition to the park near Maroota.

Habitat – in the upper catchment of Wollemi Creek, *Platysace clelandii* was recorded occurring in an open forest of *Eucalyptus piperita, E. sparsifolia* and *E. punctata*, over an understorey of *Acacia longifolia, Prostanthera prunelloides, Persoonia linearis, Podolobium ilicifolium, Oxylobium arborescens, Lomatia silaifolia, Pomaderris ledifolia, Pteridium esculentum, Lepidosperma urophorum, Lomandra filiformis* and *Lepidosperma laterale*. Maryott-Brown and Wilks (1993) summarise the habitat of this species for the adjacent Yengo NP as dry sclerophyll woodland on exposed Hawkesbury Sandstone ridges, associated with *Angophora costata, Angophora bakeri, Eucalyptus punctata, Corymbia eximia, Syncarpia glomulifera, Podolobium ilicifolium, Acacia linifolia, Persoonia linearis, Pultenaea cunninghamii* and various grasses.

Threats – no threats identified.

Conservation Status – currently known from Wollemi, Yengo, and Marramarra NPs, and Parr State Recreation Area (Briggs & Leigh 1996; Maryott-Brown and Wilks 1993).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RCa**

71. *Pomaderris bodalla* N.G.Walsh & F.Coates (Rhamnaceae)

Distribution within Wollemi – recorded on the slopes of Woodlands Trig. (a basalt knoll) along the northern escarpment of the park. While only a few plants were noted, it is possible that further populations occur in the area.

Habitat – open forest of *Eucalyptus moluccana, Eucalyptus punctata, Eucalyptus beyeriana, Grevillea montana, Dodonaea viscosa* var. *cuneata, Notelaea microcarpa* var. *microcarpa, Aristida vagans, Pratia purpurascens, Aristida ramosa, Lagenophora stipitata, Lomandra confertifolia* subsp. *rubiginosa, Gahnia aspera, Joycea pallida* and *Veronica plebeia*.

Threats – no threats identified.

Conservation Status – Walsh and Coates (1997) suggested a conservation code of 2R for this recently described species, although more recent collections from the Hunter Valley suggest a revision to 3RC- (Bell 2001). On the South Coast of NSW, Walsh and Coates (1997) indicated that *Pomaderris bodalla* was apparently endemic to the area between Nerrigundah and Brogo, where it grows in sheltered sites (gullies and streambanks) in moist open forest, within an altitudinal range of 40–350m ASL. The species occurs in Bodalla State Forest, but is not mentioned for formal reserves in that area. Other collections have also been made from Wingen Maid Nature Reserve near Scone in the upper Hunter Valley (Hill, Peake, Bell & Raine 2001).

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2R (Walsh & Coates 1997); 3RC- (Bell 2001)**

72. *Pomaderris brunnea* Wakef. (Rhamnaceae)

Distribution within Wollemi – only known from the Tea Tree Flat area in the central west of the park, and the Culoul Range in the south-east (1966 DECC Atlas record).

Habitat – At Tea Tree Flat, *Pomaderris brunnea* occurred as scattered plants in a riparian forest of *Eucalyptus cypellocarpa, E. elata,* and *Angophora floribunda*, over a tall shrub layer of *Acacia parramattensis* and *Acacia obliquenerva*. Ground layer vegetation included the ferns *Pteridium esculentum* and *Calochlaena dubia*, together with the herbs *Lomandra longifolia, Geranium homeanum, Dichondra repens, Galium propinquum, Veronica plebeia, Desmodium varians*, and *Ajuga australis*. Maryott-Brown and Wilks (1993) report this species from open forests and woodlands in association with *Eucalyptus amplifolia, Angophora floribunda, Acacia parramattensis, Bursaria spinosa* and *Kunzea ambigua*.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) indicate that this species occurs only in Wollemi NP, where population sizes are largely unknown.

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **2VC-**

73. *Pomaderris pauciflora* Wakef. (Rhamnaceae)

Distribution within Wollemi – collected at Hoolem Boy Point in the western section of the park in 1969, but no further details are available.

Habitat – Harden (1990b) states that this species often grows near streams, on the ranges south of Merriwa, and in the Braidwood district to the south.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list this species as occurring only in Deua NP in NSW, and in Coopracambra State Park in Victoria.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **3RC-**

74. *Pomaderris precaria* N.G. Walsh & F. Coates (Rhamnaceae)

Distribution within Wollemi – Scattered plants recorded from Oz Mountain in the west of the park (Bell 1998). Walsh and Coates (1997) earlier indicated that this species had not been collected from Wollemi since 1966, and that the species was in a precarious reservation state.

Habitat – Associated species at Oz Mountain were *Eucalyptus sparsifolia* and *E. punctata* in the canopy, *Dodonaea boronifolia, Prostanthera prunelloides, Boronia anethifolia, Isopogon dawsonii, Hakea dactyloides, Poranthera corymbosa, Acacia linearifolia* and *Acacia buxifolia* in the shrub layer, and with a ground cover of *Lomandra confertifolia* subsp. *rubiginosa, Stypandra glauca, Dampiera lanceolata, Joycea pallida, Lepidosperma laterale* and *Phyllanthus hirtellus*. Other collections of this species in Goulburn River NP (Bell 1997d) and the Myambat Logistics Company Site at Denman (Fallding et al. 1997) occur in similar habitat, suggesting that this species may be distributed sporadically in sheltered localities along much of the western escarpment of Wollemi.

Threats – no threats identified.

Conservation Status – listed 2VC- when described by Walsh and Coates (1997). Bell (2001) suggested a revision of this code to 2EC-, and that consideration be given to the listing of this species as Vulnerable under Schedule 2 of the NSW TSC Act, to better reflect the small sizes of known populations and their susceptibility to local extinction. Despite the potential for several populations to occur along the western escarpment of the park, it is unlikely that the combined total of all populations exceeds 1000 plants (Bell 2001).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **VU D1 (proposed);** *ROTAP*: **2VC- (Walsh & oates 1997); 2EC- (Bell 2001)**

75. *Pomaderris sericea* Wakef. (Rhamnaceae)

Distribution within Wollemi – collected at one location in the Benjang Gap area in the north-west corner of the park in 1997 by the author (confirmed by Neville Walsh). Previously known in NSW only from Berrima at the turn of the 20th century (Harden 1990b). The Wollemi find extends the known range of this species well north of Berrima, and confirms its existence in NSW.

Habitat – At Benjang Gap, approximately 15 plants in a narrow gorge along a small creekline.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) indicated that this species was presumed extinct on the NSW Central Tablelands, although there are inadequately conserved populations in Coopracambra State Park, Victoria. Bell (2001) has suggested that the conservation risk code in NSW be amended to include 51Ci (Wollemi NP).

EPBC Act: **Vulnerable;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN D1 (proposed);** *ROTAP*: **3VCi**

76. *Pomaderris* sp. aff. *nitidula (Glen Gallic)* (Rhamnaceae)

Distribution within Wollemi – Collections of an unknown *Pomaderris* species in the Glen Gallic area in the north of the park, may represent a new species. Specimens were deemed to display characteristics of the North Coast and Northern Tablelands species *Pomaderris nitidula*, but were considered to not represent typical examples of this species (N.Walsh, National Herbarium of Victoria, *pers. com.*). The nearest known locality of *Pomaderris nitidula* to Wollemi is in the Nightcap Range and north of Mt Seaview, near Port Macquarie (Harden 1990b).

Habitat – sheltered forest of *Eucalyptus moluccana*, *Eucalyptus blakelyi*, *Indigofera coronifolia*, *Solanum brownii*, *Acacia parvipinnula*, *Acacia implexa*, *Bursaria spinosa*, *Sigesbeckia australiense*, *Dichondra repens*, *Galium gaudichaudii*, *Hydrocotyle tripartita*, *Lomandra longifolia*, *Desmodium varians*, *Digitaria ramularis*, *Cyperus gracilis* and *Ajuga australis*.

Threats – no threats identified.

Conservation Status – Further information on the taxonomy and distribution of this taxon is required to determine its conservation status.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **not listed; 2KC (proposed)**

77. *Prostanthera cryptandroides* Cunn. ex Benth. (Lamiaceae)

Distribution within Wollemi – recorded from the Coxs Gap area in the north-west, as well as from the slopes of Glen Trig., and Mount Gundangaroo near Glen Davis in the west (DECC Atlas; Gibson 2002). Other recent finds are from Crypt Hill (Gibson 2002), and immediately north of Wollemi at the Myambat Logistics Company Site near Denman (Fallding et al. 1997).

Habitat – occurs sporadically in dry open forest or rocky heath in low rainfall areas along much of the western sections of Wollemi. NPWS (2000a) note habitats for *Prostanthera cryptandroides* at Glen Davis as consisting of open forest dominated by *Eucalyptus fibrosa*, with *E. albens*, *E. crebra*, *E. dawsonii*, *E. punctata* and *Callitris endlicheri*, as well as in pagoda rock formations. To the immediate north of Wollemi, it occurs in open forest of *Eucalyptus dwyeri*, *E. fibrosa*, *E. punctata*, *Acacia doratoxylon* and *Allocasuarina verticillata*; open heath/scrubland of *Calytrix tetragona*, *Isopogon dawsonii*, *Leptospermum parvifolium*, *Acacia crassa*, *Acacia doratoxylon* and *Callitris endlicheri*; and other ecotonal communities where *Acacia triptera*, *Micromyrtus sesilis*, *Baeckea densifolia*, *Dillwynia floribunda*, *Aotus ericoides* and *Hemigenia cuneifolia* occur (NPWS 2000a).

Threats – no threats identified.

Conservation Status – A revision of *Prostanthera cryptandroides*, *P. euphrasioides*, and *P. odoratissima* by Conn (1999) re-evaluated the relationships within this complex, and concluded that a single species with two subspecies is involved (*Prostanthera cryptandroides* subsp. *cryptandroides*, and subsp. *euphrasioides*). Subsp. *cryptandroides* is restricted to the Central Tablelands and Central Western Slopes between Lithgow and Sandy Hollow, but both occur on dry rocky sandstone ridges (Conn 1999). Briggs and Leigh (1996) applied a conservation code of 2RC-t for *P. cryptandroides*, indicating that the total known population is contained within conservation reserves (Wollemi and Blue Mountains NP's, both unknown in size). Recently, Washington (2001a) has recorded this species at a single location within Gardens of Stone NP to the south-west of Wollemi. Conn (1999) has suggested that neither subspecies is common and that subsp. *cryptandroides* has a very restricted distribution. Bell (2001) has documented the suggested revision of this species to 2VC- to indicate that the species is present outside of conservation reserves, and to reflect the listing of this species in NSW on the TSC Act.

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2RC-t; 2VC- (Bell 2001)**

78. *Prostanthera discolor* R.Baker. (Lamiaceae)

Distribution within Wollemi – During remote helicopter survey near Cousins Creek in the north-west of Wollemi, *Prostanthera discolor* was found to be locally common in basalt-influenced colluvial sandstone soils on an upper slope. Gibson (2002) has disputed the identity of these specimens, referring them instead to a form of *Prostanthera ovalifolia* sens. lat. However, the presence of relatively dense hairs on the calyx of the original collections would place them closer to *P. discolor*, and it may be that both species are present. Gibson (2002) also notes the presence of *Prostanthera discolor* in one of the main tributaries of Bacrami Creek in 1988. Other records of the species exist for the dry sandstone area north-west of Coxs Gap in the extreme north of the park where it abutts Goulburn River NP (DECC Atlas), although no further details of habitat or population size are known.

Habitat – At Cousins Creek, relatively dense stands of *Prostanthera discolor* occurred below a canopy of *Eucalyptus albens*, *E. punctata* and *Callitris glaucophylla*, with other understorey species including the shrubs *Dodonaea viscosa* subsp. *cuneata*, *Acacia uncinata*, *Indigofera coronifolia*, *Pomaderris angustifolia*, *Melichrus urcealatus*, *Cassinia compacta* and *Macrozamia reducta*, and the herbs *Hibbertia acicularis*, *Senecio linearifolius*, *Daucus glochidiatus*, *Hydrocotyle tripartita*, *Plantago debilis*, *Hypericum gramineum*, *Dichondra repens*, *Stellaria pungens*, *Asplenium flabellifolium*, *Galium propinquum*, *Stackhousia monogyna* and *Oplismenus imbecillis*. Unfortunately, inclement weather prevented reconnaisance of the wider population of *Prostanthera discolor* at this location; however it is likely that at least 50–80 plants were present.

Threats – no threats identified.

Conservation Status – listed as occurring only in Goulburn River NP (Briggs & Leigh (1996).

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2VC-**

79. *Prostanthera hindii* B.J.Conn (Lamiaceae)

Distribution within Wollemi – recorded in pagoda heath vegetation at three locations along the western edge of the park; Lee Creek, Dunns Swamp and Rocky Creek near the Newnes Plateau.

Habitat – In his description of the species, Conn (1997) suggests that *Prostanthera hindii* is confined to *Eucalyptus* woodlands with an understorey of *Lepidosperma* sp., *Leptospermum* sp., *Leucopogon* sp., *Platysace* sp. and *Calytrix tetragona*, occurring in quartz-rich sandy soil of rocky sandstone or conglomerate platforms and outcrops, amongst steep rocky turret faces and deep rubble-filled fissures. In the

Lee Creek catchment to the north (currently known northern limit), this species occurs with *Caustis pentandra, Allocasuarina gymnanthera, Leptospermum parvifolium, Leptospermum arachnoides, Ochrosperma monticola, Philotheca salsolifolia, Baeckea densifolia, Banksia penicillata, Isopogon dawsonii, Homoranthus cernuus, Leucopogon muticus, Dillwynia sericea, Styphelia triflora, Eucalyptus dwyeri, Callitris rhomboidea, Lepidosperma viscidum, Pomax umbellata* and *Boronia rigens*. Near Dunns Swamp, associated species inlcude *Leptospermum parvifolium, Calytrix tetragona, Kunzea ambigua, Eucalyptus multicaulis, Platysace lanceolata, Acacia decora, Leucopogon muticus, Pultenaea* sp. E, *Brachyloma daphnoides* subsp. *daphnoides, Leptospermum arachnoides, Dillwynia floribunda* var. *teretifolia, Schoenus ericetorum, Lomandra confertifolia* subsp. *rubiginosa, Chloanthes stoechadis* and *Aristida ramosa*. In the Rocky Creek area of the Newnes Plateau, *Prostanthera hindii* occurs with *Banksia ericifolia, Allocasuarina nana, Dillwynia floribunda* var. *teretifolia, Leptospermum parvifolium, Calytrix tetragona, Cryptandra propinqua, Petrophile pulchella, Leptospermum arachnoides, Acacia hamiltoniana, Schoenus ericetorum, Dampiera stricta, Stylidium lineare, Hakea laevipes* and *Hakea propinqua*. There is considerable variation in associated species in these pagoda heath environments, reflecting the variation in elevation and rainfall along the western regions of Wollemi. Populations estimates were not made at any location, and it is likely that this species occurs in many of the pagoda heath systems along the west of the park.

Threats – no threats identified.

Conservation Status – Conn (1997) noted the unknown status of this species at the time, and suggested a conservation risk code of 2RCi. A revised conservation risk code of 2RCa has been suggested by Bell (2001). Washington (2001a) recently recorded this species near Mt Jamison and at Point Cameron within Gardens of Stone NP, adjacent to Wollemi in the south-west.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2KC-; 2RCi (Conn 1997); 2RCa (Bell 2001)**

80. *Prostanthera* sp. A (Rylstone) (Lamiaceae)

Distribution within Wollemi – hills and ranges near Rylstone and Dunns Swamp.

Habitat – in *Callitris endlicheri-Eucalyptus rossii* forest in sandy loamy soils amongst sandstone outcrops (Conn (1992b). No conservation risk code has yet been assigned or suggested for this species, although it does occupy a restricted distribution in and around western Wollemi. In pagoda heath at Dunns Swamp, *Prostanthera* sp. A occurs with *Leptospermum arachnoides, Calytrix tetragona, Leptospermum parvifolium, Leucopogon muticus, Leucopogon microphyllus* subsp. *pilibundus, Leptospermum sphaerocarpum, Grevillea evansiana, Ochrosperma monticola, Dillwynia sericea, Callitris rhomboidea, Eucalyptus laophila* and *Laxmannia gracilis*.

Threats – no threats identified.

Conservation Status – Based on existing records, it is suggested that *Prostanthera* sp. A (Rylstone) be assigned a conservation risk code of 2KC- until further investigation can determine the extent of populations within Wollemi.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **not listed; 2KC- (proposed)**

81. *Prostanthera* sp. aff. *rotundifolia (Mt Iris)* (Lamiaceae)

Distribution within Wollemi – Mt Iris-Gospers Mountain area in the west.

Habitat – shallow sandy soils in open forest of *Eucalyptus punctata, Eucalyptus sparsifolia, Eucalyptus beyeriana, Acacia longifolia, Cassinia cunninghamii, Allocasuarina littoralis, Acacia penninervis, Lepidosperma laterale, Lomandra confertifolia* subsp. *rubiginosa, Hibbertia circumdans, Dianella caerulea* and *Lomandra filiformis* subsp. *filiformis*.

Threats – no threats identified.

Conservation Status – relatively common in the Mt Iris-Gospers Mountain area and possibly represents a new species (B.Conn, National Herbarium of NSW, *pers. comm.*). Specimens collected have superficial similarities to *Prostanthera rotundifolia*, but differ in floral arrangement and leaf size. Further investigation is currently underway.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **not listed; 2KC- (proposed)**

82. *Prostanthera stricta* R. Baker (Lamiaceae)

Distribution within Wollemi – Conn (1992b) describes *Prostanthera stricta* as occuring only in the Widden Valley district, where it grows in sandy alluvium near watercourses. During surveys of Wollemi NP, this species was not recorded here nor anywhere else in the park (Bell 1998). Gibson (2002) considers the Wollemi material to be a separate species with close affinities to *P. stricta*, and reports it for the creeklines around Mt Monundilla and Gundy Wattle Flat.

Habitat – *Prostanthera* sp. aff. *stricta* (see note below) occurs on Narrabeen Sandstone geology, as well as Quaternary alluvial and colluvial material. NPWS (2000b) report that it can be locally dominant, and can grow at the base of conglomerate slopes and cliffs, on ledges and in crevices, sandy colluvium at the base of cliffs, in fluvial depositional zones, on sandy alluvial deposits and on rocky side slopes. Associated species include *Backhousia myrtifolia, Cryptandra buxifolia, Isopogon dawsonii* and *Leucopogon muticus* in a low scrub; open forest of *Eucalyptus caleyi, E. punctata, E. sideroxylon, Allocasuarina torulosa* and *Macrozamia communis*; open forest of *Eucalyptus tereticornis, E. sideroxylon, Angophora floribunda, Acacia caesiella* and *Callistemon salignus*; and open forest of *Angophora floribunda, Eucalyptus fibrosa* and *E. punctata*.

Threats – no threats identified.

Conservation Status – Gibson (2002) considers the material growing in Dingo Creek and the Widden and Baerami Valleys within the park to be distinct from *Prostanthera stricta s. str.*, the latter species restricted to Mount Vincent and Genowlan Mountain (outside of reserve). The two taxa differ in that the Wollemi specimens have broad-ovate to ovate leaves, leaf bases which are often broadly rounded, and a longer and greater density of indumentum on the whole plant (NPWS 2000b). In addition, only *Prostanthera* sp. aff. *stricta* has been observed to reproduce vegetatively, with the layering of branches when growing in riparian situations.

EPBC Act: **Vulnerable;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU D2 (proposed);** *ROTAP*: **2V**

83. *Pseudanthus divaricatissimus* (Muell. Arg.) Benth. (Euphorbiaceae)

Distribution within Wollemi – recorded only around Newnes in the south-west of the park.

Habitat – James & Harden (1990) indicate that this species grows on rocky ground at higher altitudes. Washington (2001a) located this species in low heath on and near the Newnes Plateau in Gardens of Stone NP.

Threats – no threats identified.

Conservation Status – recorded from Wollemi, Blue Mountains, Kanangra-Boyd, Budawang, Deua, and Morton NPs in NSW, and Brisbane Ranges, Snowy River, and Croajingolong NPs in Victoria (Briggs & Leigh 1996). Also from Gardens of Stone NP to the south-west of Wollemi (Washington 2001a), and Royal NP (A. Fairley, *pers. comm.*).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RCa**

84. *Pultenaea glabra* Benth. (Fabaceae: Faboideae)

Distribution within Wollemi – *Pultenaea glabra s. str.* occurs approximately 7km to the north-east, and 3km to the south, of Glen Davis in the west of the park, and around Mt Coricudgy in the centre. No information is available on the sizes of these populations, nor of their habitat attributes.

Habitat – *Pultenaea* sp. E (see notes below) has been recorded in pagoda heath in the west of the park, where it occurs as scattered plants in the shrub layer with *Leptospermum parvifolium, Calytrix tetragona, Acacia decora, Prostanthera hindii, Leucopogon muticus, Kunzea ambigua, Platysace lanceolata, Brachyloma daphnoides, Baeckea utilis,* and *Leptospermum arachnoides.* Ground layer vegetation includes *Aristida ramosa, Lomandra confertifolia* subsp. *rubiginosa, Schoenus ericetorum, Hibbertia circumdans,* and *Chloanthes stoechadis.*

Threats – no threats identified.

Conservation Status – A recent revision of the *Pultenaea* genus has shown that specimens previously determined as *Pultenaea* sp. E (as in Weston 1991), *Pultenaea wiendorferi* (as in Corrick 1996) and *Pultenaea* sp. 'Olinda' (see below) should now be considered within the limits of *Pultenaea glabra* (de Kok & West 2002). These authors also state that *Pultenaea glabra* is consequently more widespread then previously thought, and suggest that a revision of the current conservation risk code is required. However, Peter Weston (National Herbarium of NSW) is of the opinion that several forms within this complex may indeed warrant recognition at the specific rank (Weston & de Kok 2002). Briggs and Leigh (1996) list this species as occurring in Wollemi and Blue Mountains NPs, both of which are considered to support adequate populations. De Kok and West (2002) also include Goulburn River NP in New South Wales, and also Kinglake NP and Gembrook Regional Park in Victoria (as *Pultenaea weindorferi*).

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **3VCa**

85. *Pultenaea* sp. "Olinda" (Coveny 6616) (Fabaceae: Faboideae)

Distribution within Wollemi – occurs only in a very limited area of pagoda rock formation east of Rylstone from Currant Mountain Gap to Nullo Mountain (Weston & de Kok 2002). Two populations approximately 3km apart are also present in the Spring Log Ridge area.

Habitat – at Spring Log Ridge, this species occurs on ledges and in crevices at the base of small clifflines (S. Clarke, pers. comm.).

Threats – no threats identified.

Conservation Status – De Kok and West (2002) are of the opinion that this taxon, together with the endangered *Pultenaea* sp. 'Genowlan Point', are geographical variants of *Pultenaea glabra.* However, there is still some uncertainty concerning the latest revision, and it is suggested that this taxon should be treated as distinct.

EPBC Act: **not listed;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN B1 (proposed);** *ROTAP*: **2EC- (proposed)**

86. *Rulingia hermanniifolia* (DC.) Endl. (Sterculiaceae)

Distribution within Wollemi – one record exists within the DECC Atlas from 1975 for the slopes of Mt Towinhingy, near Dunns Swamp, in the western sections of Wollemi. This record may possibly be in error, as this area is well outside of the species' generally accepted more coastal range. Field investigations are required at this location to confirm its status.

Habitat – no information is available for this location.

Threats – no threats identified.

Conservation Status – recorded from Botany Bay, Bouddi, Ku-ring-gai Chase, Royal, Sydney Harbour, Morton, Jervis Bay, and (in Victoria) Girraween NPs, as well as Captains Cook Landing Place Historic Site (Briggs & Leigh 1996).

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **3RCa**

87. *Rulingia* sp. aff. *dasyphylla* (Sterculiaceae)

Distribution within Wollemi – found in sheltered forest on alluvial soils in remote areas of northern Wollemi during helicopter-based surveys. Initially collected from locations within Goulburn River NP and Crown reserve to the north of Wollemi near Sandy Hollow (Bell 1997a).

Habitat – open forest of *Angophora floribunda, Eucalyptus blakelyi, E. punctata, Allocasuarina torulosa, Bursaria spinosa, Breynia oblongifolia, Hydrocotyle laxiflora, Pratia concolor, Asplenium flabellifolium, Adiantum aethiopicum* and *Ajuga australis.* In Goulburn River NP, it occurs in mallee woodland of *Eucalyptus aenea, Acacia muelleriana, Acacia doratoxylon, Dodonaea triangularis, Acrotricha rigida, Allocasuarina littoralis, Dillwynia juniperina, Phyllanthus hirtellus, Goodenia rotundata* and *Panicum subxerophilum* (Bell 1997d).

Threats – no threats identified.

Conservation Status – members of the *Rulingia* genus are currently undergoing revision; the status of this taxon is unknown.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **not listed; 2KC (proposed)**

88. *Rupicola ciliata* Telford (Epacridaceae)

Distribution within Wollemi – a single DECC Atlas record from 2001 for Tootie Creek, in the southern section of the park.

Habitat – Powell (1992) reports that this species grows in skeletal sandy soils in rock crevices, on rock ledges, and beneath cliff overhangs in the Kurrajong Heights, Bilpin, and lower Yarramun Creek districts in the Blue Mountains.

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) indicate that Wollemi and Blue Mountains NPs support the only known populations of this species.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RCt**

89. *Rupicola decumbens* Telford (Epacridaceae)

Distribution within Wollemi – recorded only near the Glow-worm tunnel in the south-west in the Glen Davis and Cudgegong River areas (1995 DECC Atlas record).

Habitat – occurs in skeletal sandy soils on rock ledges, cliff faces, and at the base of sandstone cliffs at 550–950 m altitude (Powell 1992).

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) list only Wollemi NP.

EPBC Act: **not listed;** *TSC Act*: **not listed;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2RC-**

90. *Swainsona recta* A.Lee. (Fabaceae: Faboideae) Mountain Swainsona-pea

Distribution within Wollemi – a single DECC Atlas record for Nullo Mountain (1987) in the central-west of the park.

Habitat – grassland and open woodland, often on stony hillsides (Thomson 1993).

Threats – grazing by adjacent landowners.

Conservation Status – Briggs and Leigh (1996) indicate that this species occurs in Burrendong SRA and Mt Arthur Reserve on the Central Western Slopes.

EPBC Act: **Endangered;** *TSC Act*: **Endangered;** *IUCN (2001)*: **DD (proposed);** *ROTAP*: **3EC-**

91. *Tetratheca glandulosa* Smith (Tremandraceae) A Black-eyed Susan

Distribution within Wollemi – hills above Upper Colo and around Mountain Lagoon.

Habitat – open forest or woodland of *Eucalyptus sparsifolia, Angophora costata, Corymbia gummifera,* and *Eucalyptus punctata.* Occassional *Corymbia eximia* and *Angophora bakeri* may also occur at more exposed aspects. Understorey vegetation is typically dense, and includes shrub species such as *Kunzea ambigua, Boronia ledifolia, Phyllota phylicoides, Platysace linearifolia, Dillwynia floribunda* var. *teretifolia, Persoonia linearis, Lambertia formosa, Lomatia silaifolia, Banksia spinulosa* var. *spinulosa,* and *Hakea sericea,* and the ground layer plants *Entolasia stricta, Lomandra obliqua, Caustis flexuosa, Patersonia glabrata* and *Lindsaea microphylla.* Reported in association with *Angophora bakeri, Corymbia gummifera, Banksia serrata, Banksia spinulosa, Leptospermum trinervium, Hakea dactyloides,* and *Dillwynia floribunda* in Yengo NP (Maryott-Brown & Wilks (1993).

Threats – no threats identified.

Conservation Status – Briggs and Leigh (1996) state that this species is represented within Dharug, Ku-ring-gai Chase, and Garigal NPs, while Maryott-Brown and Wilks (1993) list the species for Yengo NP. Latham (1995) also notes the species for a number of proposed Nature Reserves and NPs in Greater Sydney. It is also present in Popran NP (Bell 1998), and James (1997) notes unsubstantiated records for Cattai NP.

EPBC Act: **not listed;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **LC (proposed);** *ROTAP*: **2VC-**

92. *Velleia perfoliata* R.Br. (Goodeniaceae)

Distribution within Wollemi – recorded from the Wheeny Creek and Morans Rocks area, in the south-east of the park (DECC Atlas), and from the base of Bob Turner's Track near Colo Heights (A. Fairley, *pers. comm.*).

Habitat – for eastern Yengo NP, Maryott-Brown and Wilks (1993) describe the habitat as sandstone rock platforms surrounded by *Angophora bakeri, Corymbia gummifera, Banksia serrata, Leptospermum parvifolium, Hakea dactyloides, Pultenaea villosa* and *Lepidosperma laterale.*

Threats – mistaken for weeds and uprooted.

Conservation Status – A Species Recovery Plan has been completed (Maryott-Brown 1994a); also occurs in adjacent Yengo NP (Briggs & Leigh 1996; Maryott-Brown & Wilks 1993).

EPBC Act: **Vulnerable;** *TSC Act*: **Vulnerable;** *IUCN (2001)*: **VU B2ac(iv); D1 (proposed);** *ROTAP*: **2VC-**

93. *Wollemia nobilis* W.D.Jones, K.D.Hill & J.M.Allen (Araucariaceae) Wollemi Pine

Distribution within Wollemi – a few locations comprising less than 100 adults within two catchments (Ravallion 2000; DEC 2006)

Habitat – all stands occur in deep narrow sandstone gorges in warm temperate rainforest of *Ceratopetalum apetalum, Doryphora sassafras* and *Acmena smithii,* with an understorey comprising several fern species such as *Dicksonia antarctica, Cyathea australis, Sticherus flabellatus, Adiantum diaphanum, Doodia aspera* and *Blechnum nudum* (Benson & Allen 2007). Tall eucalypt woodland dominated by *Eucalyptus piperita* surrounds these areas (Jones et al. 1995). See Jones, Hill and Allen (1995), Hill (1997a), Gilmore and Hill (1997), and Offord and Meagher (2001) for further details on ecology.

Threats – dieback from the pathogen *Phytophthora cinnamomi* and potentially threatened by the further introduction of plant pathogens and weeds, soil compaction, seedling damage, collectors and catastrophic fire events. Stands may also be threatened by changes to the habitat through the effects of climate change (DEC 2006a).

Conservation Status – A Species Recovery Plan for *Wollemia nobilis* has been completed (DEC 2006a), and a Declaration of Critical Habitat has been legislated (DEC 2007).

EPBC Act: **Endangered;** *TSC Act*: **Endangered;** *IUCN (2001)*: **CR D;** *ROTAP*: **2ECit-**

94. *Zieria involucrata* R.Br. ex Benth. (Rutaceae)

Distribution within Wollemi – south-eastern sections of Wollemi, in the Colo Heights area (DECC Atlas).

Habitat – In southern Yengo NP, Maryott-Brown and Wilks (1993) indicate that this species occurs in sheltered forests on lower slopes in association with *Syncarpia glomulifera, Angophora costata* and *Allocasuarina torulosa,* with an understorey of *Ceratopetalum gummiferum, Backhousia myrtifolia, Acacia linifolia, Calochlaena dubia, Entolasia stricta* and *Lomandra* spp. Benson and McDougall (2001) indicate that this species occurs on steep sandy slopes and on ridges, within moist open forest of *Angophora costata, Syncarpia glomulifera, Eucalyptus punctata, E. piperita, Allocasuarina torulosa* and *Eucalyptus oreades.*

Threats – inappropriate fire, weed invasion, clearing for urban development (DEC 2006b).

Conservation Status – Briggs and Leigh (1996) state that this species is represented within Blue Mountains, Marramarra, and Yengo NPs, with extensive populations in Parr State Recreation Area. Maryott-Brown (1994b) has prepared a Conservation Research Statement and recovery plan.

EPBC Act: **not listed;** *TSC Act*: **Endangered;** *IUCN (2001)*: **EN A1a; B1 (proposed);** *ROTAP*: **2VCa**

Table 4. Rare or threatened plant species of Wollemi National Park listed by proposed IUCN and ROTAP codes.
IUCN Codes: Critically Endangered = CR; Endangered = EN; Vulnerable = VU; Near Threatened = NT; Least Concern = LC; Data Deficient = DD (IUCN 2001).

Species	IUCN (2001)	EPBC Act	TSC Act	ROTAP code	
	Proposed here			Current	Proposed here
Critically Endangered CR					
Wollemia nobilis	[CR D]	E	E	2Ecit	-
Eucalyptus sp. 'Howes Swamp Creek' (Doherty 26)	CR D1	E	E	2ECi	-
Endangered EN					
Zieria involucrata	EN A1a; B1	V	E	2VCa	-
Macrozamia elegans	EN A2ad			-	[2VC-]
Persoonia hirsuta var. *evoluta*	EN B1	E	E	3Kci	-
Persoonia marginata	EN B1	V	V	2V	-
Pimelea curviflora var. *curviflora*	EN B1	V	V	-	2VC-
Pultenaea sp. (Olinda)	EN B1		E	-	2EC-
Asterolasia elegans	EN C2b	E	E	2Eca	-
Baeckea kandos	EN D1	E	E	2RC-t	-
Gyrostemon thesioides	EN D1		E	-	2EC
Haloragodendron gibsonii	EN D1	E	E	2Rcat	-
Pomaderris sericea	EN D1	V	E	3VCi	-
Vulnerable VU					
Acacia pubescens	VU A2bc	V	V	3VCa	-
Ozothamnus tesselatus	VU B1	V	V	2VC-	-
Olearia cordata	VU B1; C2b	V	V	2VCi	-
Velleia perfoliata	VU B2ac(iv); D1	V	V	2VC-	-
Melaleuca deanei	VU C2(ai)	V	V	3RC-	-
Melaleuca groveana	VU C2(ai); D2		V	3RC-	-
Pomaderris precaria	VU D1			-	[2VC-] [2EC-]
Grevillea obtusiflora subsp. *obtusiflora*	VU D1+2	E	E	2E	-
Leptospermum spectabile	VU D1+2			2RC-	2RCt
Cynanchum elegans	VU D2	E	E	3ECi	-
Epacris coriacea	VU D2			3RC-	-
Epacris muelleri	VU D2			3RC-	-
Eucalyptus aenea	VU D2			2RC	[2RC-}
Eucalyptus bensonii	VU D2			2RC-t	-
Eucalyptus burgessiana	VU D2			2RCa	-
Eucalyptus corticosa	VU D2		V	-	2VC-
Isotropis foliosa	VU D2			3KC-	-
Leionema scopulinum	VU D2			-	[2RCit]
Pentachondra dehiscens	VU D2			-	[3RC]
Pomaderris bodalla	VU D2		V	-	[2R]
Prostanthera cryptandroides	VU D2	V	V	2RC-t	[2VC-]
Prostanthera discolor	VU D2	V	V	2VC-	-
Prostanthera stricta	VU D2	V	V	2V	-
Near Threatened NT					
Acacia bynoeana	NT	V	E	3VC-	-
Acacia gordonii	NT	E	E	2K	-
Leionema sympetalum	NT	V	V	2VC-	-
Least Concern LC					
Acacia asparagoides	LC			2R	-
Acacia bulgaensis	LC			2RC-	-
Acacia flocktoniae	LC	V	V	2VC-	-
Acacia fulva	LC			2RC-	2RCa
Acacia matthewii	LC			3RC-	-
Acacia subtilinervis	LC			3RCa	-
Almaleea incurvata	LC			2RC-t	2RC-
Apatophyllum constablei	LC	E		2EC-	2RCa

Atkinsonia ligustrina	LC			2RCa	-
Banksia penicillata	LC			3RC-	-
Boronia floribunda	LC			-	[2RC-]
Boronia fraseri	LC			2RCa	-
Boronia rubiginosa	LC			2RCa	-
Callistemon shiressii	LC			3RC-	-
Darwinia peduncularis	LC		V	3RCi	-
Eucalyptus cannonii	LC	V	V	2VCi	[2RCa]
Eucalyptus fergusonii subsp. *dorsiventralis*	LC			2RC-	-
Eucalyptus hypostomatica	LC			3RC-	-
Eucalyptus prominula	LC			2KC-	-
Gonocarpus longifolius	LC			3RC-	[3RCa]
Grevillea evansiana	LC	V	V	2VC-	2VCa
Grevillea johnsonii	LC			-	2RCi [2RCa]
Grevillea montana	LC			2KC-	[2RCa]
Homoranthus cernuus	LC			2RCa	-
Leucochrysum graminifolium	LC			2R	2RC-
Lissanthe sapida	LC			3RCa	-
Lomandra fluviatilis	LC			3RCa	-
Olearia quercifolia	LC			3RC-	-
Philotheca obovalis	LC			3RCa	-
Platysace clelandii	LC			2RCa	-
Prostanthera hindii	LC			2KC-	-
Pseudanthus divaricatissimus	LC			3RCa	-
Rulingia hermanniifolia	LC			3RCa	-
Rupicola ciliata	LC			2RC-t	-
Rupicola decumbens	LC			2RC-	-
Tetratheca glandulosa	LC	V	V	2VC-	-

Data Deficient DD

Blechnum gregsonii	DD			2RCa	-
Boronia barkeriana subsp. *barkeriana*	DD			-	[2RC-]
Brasenia schreberi	DD			3RC-+	-
Cyphanthera scabrella	DD			2RC-	-
Diuris sp. aff. *punctata* (Colo River)	DD			-	2KC
Eucalyptus gregsoniana	DD			3RCa	-
Eucalyptus sp. aff. *eugenioides* (Bees Nest Ridge)	DD			-	3KC
Kennedia retrorsa	DD	V	V	2VCa	2VCi
Keraudrenia corollata var. *denticulata*	DD			3RC-	-
Leionema lamprophyllum subsp. *orbiculare*	DD			-	[2R-]
Leionema sp. 'Colo River' (Weston 2423)	DD			-	[2VC-]
Pomaderris brunnea	DD	V	V	2VC-	-
Pomaderris pauciflora	DD			3RC-	-
Pomaderris sp. aff. *nitidula* (Glen Gallic)	DD			-	2KC
Prostanthera sp. A (Rylstone)	DD			-	2KC-
Prostanthera sp. aff. *rotundifolia*. (Mt Iris)	DD			-	2KC-
Pultenaea glabra	DD	V	V	3VCa	-
Rulingia sp. aff. *dasyphylla* (Goulburn River Valley)	DD			-	2KC
Swainsona recta	DD	E	E	3ECi	-*Apatophyllum*
constablei	LC	E		2EC-	2RCa
Atkinsonia ligustrina	LC			2RCa	-
Banksia penicillata	LC			3RC-	-
Boronia floribunda	LC			-	[2RC-]
Boronia fraseri	LC			2RCa	-
Boronia rubiginosa	LC			2RCa	-
Callistemon shiressii	LC			3RC-	-
Darwinia peduncularis	LC		V	3RCi	-
Eucalyptus cannonii	LC	V	V	2VCi	[2RCa]
Eucalyptus fergusonii subsp. *dorsiventralis*	LC			2RC-	-
Eucalyptus hypostomatica	LC			3RC-	-
Eucalyptus prominula	LC			2KC-	-
Gonocarpus longifolius	LC			3RC-	[3RCa]
Grevillea evansiana	LC	V	V	2VC-	2VCa
Grevillea johnsonii	LC			-	2RCi [2RCa]
Grevillea montana	LC			2KC-	[2RCa]

Homoranthus cernuus	LC			2RCa	-
Leucochrysum graminifolium	LC			2R	2RC-
Lissanthe sapida	LC			3RCa	-
Lomandra fluviatilis	LC			3RCa	-
Olearia quercifolia	LC			3RC-	-
Philotheca obovalis	LC			3RCa	-
Platysace clelandii	LC			2RCa	-
Prostanthera hindii	LC			2KC-	-
Pseudanthus divaricatissimus	LC			3RCa	-
Rulingia hermanniifolia	LC			3RCa	-
Rupicola ciliata	LC			2RC-t	-
Rupicola decumbens	LC			2RC-	-
Tetratheca glandulosa	LC	V	V	2VC-	-
Data Deficient DD					
Blechnum gregsonii	DD			2RCa	-
Boronia barkeriana subsp. *barkeriana*	DD			-	[2RC-]
Brasenia schreberi	DD			3RC-+	-
Cyphanthera scabrella	DD			2RC-	-
Diuris sp. aff. *punctata* (Colo River)	DD			-	2KC
Eucalyptus gregsoniana	DD			3RCa	-
Eucalyptus sp. aff. *eugenioides* (Bees Nest Ridge)	DD			-	3KC
Kennedia retrorsa	DD	V	V	2VCa	2VCi
Keraudrenia corollata var. *denticulata*	DD			3RC-	-
Leionema lamprophyllum subsp. *orbiculare*	DD			-	[2R-]
Leionema sp. 'Colo River' (Weston 2423)	DD			-	[2VC-]
Pomaderris brunnea	DD	V	V	2VC-	-
Pomaderris pauciflora	DD			3RC-	-
Pomaderris sp. aff. *nitidula* (Glen Gallic)	DD			-	2KC
Prostanthera sp. A (Rylstone)	DD			-	2KC-
Prostanthera sp. aff. *rotundifolia*. (Mt Iris)	DD			-	2KC-
Pultenaea glabra	DD	V	V	3VCa	-
Rulingia sp. aff. *dasyphylla* (Goulburn River Valley)	DD			-	2KC
Swainsona recta	DD	E	E	3ECi	-

Table 5. Other rare or threatened plant species recorded near Wollemi NP.

Endangered	**Nearby locations**
Acacia dangarensis	Mt Dangar (Tindale & Kodela 1991)
Asterolasia buxifolia	Hartley area (Wilson 1998a; Makinson 2002a)
Boronia ruppii	Glen Davis, Wolgan Pinnacle and East Kurrajong (Fairley 2004)
Commersonia rosea	Crown lands around Sandy Hollow (Bell & Copeland 2004)
Eucalyptus sp. "Cattai"	Colo Heights
Eucalyptus fracta	northern Yengo NP (pers. obs.)
Persoonia hindii	Newnes Plateau (Weston & Johnson 1996)
Phebalium bifidum	Capertee Valley (Weston & Turton 2004)
Pterostylis gibbosa	private land north of Yengo NP (Bradburn 2000)
Pultenaea sp. "Genowlan Point"	Genowlan Pointi
Senecio linearifolius var. *dangarensis*	Mt Dangar, Goulburn River NP (Thompson 2004)
Vulnerable	
Acrophyllum australe	northern Blue Mountains NP (DECC Atlas)
Acrotriche crassifolia	Glen Davis area (Harden 1993)
Boronia deanei subsp. *deanei*	Newnes Plateau (Benson & Keith 1990)
Darwinia biflora	Bulga (DECC Atlas, possibly in error)
Derwentia blakelyi	Nullo State Forest (pers. obs.; Benson & McDougall 2001)
Dillwynia tenuifolia	northern Yengo NP (Maryott-Brown & Wilks 1993)
Epacris sparsa	northern Blue Mountains NP (DECC Atlas)
Eucalyptus aligatrix subsp. *aligatrix*	Rylstone district
Grevillea obtusiflora subsp. *fecunda*	Gardens of Stone NP, Glen Alice (Washington 2001a)
Grevillea parviflora subsp. *parviflora*	Putty area (Fairley 2004)
Homoranthus darwinioides	Lees Pinch, Goulburn River NP
Lasiopetalum longistamineum	Mt Dangar (DECC Atlas)
Persoonia acerosa	upper Blue Mountains (DECC Atlas)
Zieria murphyi	Mt Tomah area (Armstrong 2002)
Rare	
Acacia alaticaulis ("2RC-t")	Howes Mountain, Yengo NP (Maryott-Brown & Wilks 1993)
Acacia asparagoides (2R)	Newnes Plateau and Gardens of Stone NP (Benson & Keith 1990; Washington 2001a)
Acacia meiantha (2RCi)	Clarence (Fairley 2004)
Arthrochilus prolixus (2K)	Morans Rocks (DECC Atlas)
Bothriochloa biloba (3V)	Goulburn River valley (DECC Atlas)
Bunochilus lineatus ("2VC")	Blue Mountains (Jones 2006)
Bunochilus chocolatinus ("2V")	Blue Mountains (Jones 2006)
Dianella tenuissima "(Data deficient")	Blue Mountains, Newnes Plateau (Carr 2006)
Eucalyptus michaeliana (3RCa)	Yengo NP (Maryott-Brown & Wilks 1993; Ryan et al. 1996)
Hakea constablei (2RCa)	west of Mt Irvine (DECC Atlas)
Leptospermum rupicola (3RC-)	Glen Davis, upper Blue Mountains (Benson 1990; Fairley 2004)
Lomandra brevis (2RC-)	southern Yengo NP (Maryott-Brown & Wilks 1993; Ryan et al. 1996)
Persoonia recedens (2R)	Newnes Plateau (Fairley 2004)
Prostanthera cineolifera (2K)	Yengo NP (Ryan et al. 1996)
Sphaerocionium lyallii (3RC-)	northern Blue Mountains (DECC Atlas)
Acacia leprosa (?)	Mt Tayar east of Rylstone (Fairley 2004)
Grevillea sericea subsp. *riparia* (?)	lower Grose and Colo Rivers (Makinson 2000, 2002b)

Discussion

The importance of Wollemi in conserving regionally significant taxa

Wollemi National Park supports a diverse range of vascular plant species in its 500 000 ha of sandstone forests, woodlands, heaths and rainforests. The 94 rare or threatened species presented here highlight the importance of the park in preserving taxa of restricted distribution, and it is likely that additional species and new populations will be added as survey of remote areas continues. Of the known significant flora, 37 are currently listed on the NSW TSC Act (15 as Endangered, 22 as Vulnerable). Based on data in Mokany and Adam (2000), this figure represents more than 20% of all listed threatened species for the Central Coast, Central Tablelands and Central Western Slopes botanical subdivisions (given that several species occur in more than one subdivision). The combined area of these three divisions equals 112 000 km^2 (or 1 120 000 000 ha), and Wollemi NP comprises only 0.05% of this total. The occurrence of 20% of the listed threatened species in this small proportion of these three divisions stresses the importance of Wollemi in regional conservation.

Of the 94 significant Wollemi species, the majority are considered to be adequately conserved. Bell (2001) has previously suggested amendments to the ROTAP conservation risk codes (the Briggs & Leigh 1996 system) of some of these species, based on the results from vegetation surveys in the Hunter Valley. Further amendments are now provided for several other taxa, given their large populations present within the park (Tables 3 & 4). Appropriate IUCN codes have also been attributed to all significant species - only one species (*Wollemia nobilis*) is included within the current IUCN Red List.

In recent years, new and undescribed taxa have also been located within the rugged and remote parts of Wollemi. This is exemplified in the discovery of the Wollemi Pine (*Wollemia nobilis*) in 1994, but also in new species of *Prostanthera*, *Pomaderris*, *Pentachondra* and *Eucalyptus*. While several helicopter-based surveys have been undertaken in remote locations, there is still considerable potential for further new taxa to be found.

Representation of significant *Pomaderris* species within Wollemi is considered to be of particular interest. To date, 19 species of *Pomaderris* have been recorded from the park, including one undescribed taxon and four threatened or rare species. New locations of the significant *Pomaderris precaria, Pomaderris brunnea, Pomaderris sericea,* and *Pomaderris pauciflora* have been recorded in recent years. The occurrence of the recently described *Pomaderris bodalla* from the slopes of Woodlands Trig. along the Northern Escarpment of the park represents a significant range extension from the South Coast (Walsh & Coates 1997). Other populations have been recorded recently from Wingen Maid Nature Reserve, confirming its occurrence in the region (Hill, Peake, Bell & Raine 2001). Of equal significance is the collection of *Pomaderris sericea* from Benjang Gap in the north-west of the park, representing a sizeable range extension for this Endangered species; the only other NSW location being an old collection from Berrima, and in Victoria far East Gippsland, (N.Walsh, National Herbarium of Victoria, *pers. comm.*).

It would appear from these disjunct populations of significant *Pomaderris* species, that the northern sections of Wollemi NP, particularly around the Goulburn River valley, provide important refugia for this genus. The occurrence of the highly endemic *Pomaderris reperta* from Denman adds weight to this notion; this species is apparently restricted to one ridgeline (Fallding, Bell & Murray 1997; Walsh & Coates 1997). The occurrence of *Pomaderris queenslandica* and *Pomaderris precaria* also from the Denman and Goulburn River NP areas is also noteworthy (Bell 2001). The interesting collection of *Pomaderris* sp. aff. *nitidula* from the Martindale Trail area of Wollemi is also of relevance, since *Pomaderris nitidula* occurs in the Nightcap Range to the north. Further survey for *Pomaderris* species within the Goulburn River valley is likely to add considerable knowledge to this genus.

Several other documented threatened or rare plant species are known from areas adjacent to Wollemi (less than 15km from the park boundary), and all of these potentially occur within the park (Table 3), and recent taxonomic revisions also raise the possibility of other significant species occuring within the park. Armstrong (2002) recognised *Zieria caducibracteata* as a restricted taxa occuring from the Colo River to Batemans Bay. The northern populations in the Colo River Gorge are distinct in having rounded (not acute) leaflet apices and slightly shorter leaflets. These populations occur in skeletal sandy soils in open eucalypt forests associated with understorey species such as *Prostanthera prunelloides*. Halford and Henderson (2002) described *Bertya linearifolia* as being restricted to the Denman – Sandy Hollow area, with the type collected from Upper Baerami Creek in Wollemi NP. Orchard (2004) has recently recognised *Cassinia decipiens* (previously included within *Cassinia cunninghamii*) from the Goulburn River valley, south to near Rylstone, and *Cassinia accipitrum* (previously included within *Cassinia compacta*) from the Hawkesbury and Colo River valleys, inland to Colo Heights and Mountain Lagoon. Both of these newly segregated *Cassinia* species most likely occur within Wollemi, and both occupy restricted geographical ranges. The newly described and highly restricted *Paenula storyi* from near Wollar (Orchard 2005) may also occur within Wollemi. At Glen Gallic in northern Wollemi, stunted mallee-like redgums occur which are currently attributed to *Eucalyptus dealbata* (Bell 2001). Further investigation on these specimens is required, as they occur in a small disjunct population well to the east of the main range of this species, and on infertile sandy soils on Narrabeen Sandstone, which is an unusual habitat for the species. Along the western portions of the park (such as in the Benjang Gap area), terete-leaved forms of *Lomandra multiflora* occur. Washington (2001a) has also found this form in the nearby Gardens of Stone NP (and other areas), and considered it uncommon and worthy of nomination to the *TSC Act 1995*.

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Population size, habitat and conservation status of an Endangered species, *Macrozamia johnsonii* (Zamiaceae)

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Abstract: *Macrozamia johnsonii* D. Jones & K. Hill is a locally endemic cycad (family Zamiaceae) with a restricted occurrence in north-eastern New South Wales and currently listed as Endangered. Based on recent field surveys, its mean population size is estimated as approximately 3.5 million mature plants, with the lower bound of the 95% confidence interval at 1.9 million mature plants. Thirty percent of the population occurs in a formal reserve. *Macrozamia johnsonii* occurs in grassy eucalypt forest, shrubby wet sclerophyll forest and in rainforest. It occurs most frequently on steeply sloping sites with high moisture index. There are no immediate significant threats to the species although timber harvesting is judged to be a potential longer term threat to part of the population. The conservation status of *Macrozamia johnsonii* is assessed using IUCN criteria and thresholds, using population size and extent data from this study and a plausible range of values based on available circumstantial evidence for parameters for which quantitative estimates are not available. Based on this assessment, we regard the conservation status of *Macrozamia johnsonii* to be in the category of Least Concern, and that its current listing as an Endangered species under the NSW *Threatened Species Conservation Act (1995)* needs to be revised.

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Introduction

In recent decades there has been increasing interest in compiling lists of threatened species for both practical conservation management and legislative purposes. In Australia, there is both Commonwealth (*Environmental Protection and Biodiversity Conservation Act 1999*) and State (e.g. for NSW, *Threatened Species Conservation Act 1995*) legislation which lists threatened taxa (species and infra-specific taxa) in various threat categories. These lists have a major role in determining conservation and natural resource management priorities in a very wide range of circumstances. Recently, explicit guidelines for assessment, largely modelled on the IUCN categories and criteria (IUCN 2001) have been developed. However, at least in NSW, current lists include a majority of species for which assessment criteria and thresholds have not been explicitly documented, and until very recently, there has been no public record of the details of assessment of a taxon against specific criteria. All listed species need to be assessed against IUCN criteria and assessments periodically reviewed using the same criteria, to ensure that all species are assessed consistently and that changes in status can be tracked.

Cycads as a group have a disproportionately high number of threatened species. About 60% of all cycad species were assessed as threatened by Osborne (1995), but this was revised to 52% by Donaldson (2003), who also indicated that Australia had the lowest proportion of threatened species of any of the main global regions of cycad diversity. *Macrozamia johnsonii* is a locally endemic cycad restricted to the Dalmorton area, west of Grafton, in northern New South Wales (approximately 152° 30' E; 29° 50' S), first collected by Boorman in 1907 (Johnson 1961, as *Macrozamia moorei*). In 1992 it was described (Jones & Hill 1992) as a species separate from the most similar congener, *Macrozamia moorei*, which occurs 800 km away in central Queensland. *Macrozamia johnsonii* is a large species; mature individuals have up to 120 fronds, each frond being up to 3 m long, and older plants develope a trunk to at least 2 m tall (Johnson 1961; Jones & Hill 1992).

Individuals of *Macrozamia johnsonii* (under *Macrozamia moorei*) were noted by Johnson (1961) to be "locally numerous" in NSW and regeneration was described as "copious". Jones and Hill (1992) described it as "locally common in the Dalmorton area", growing in "large colonies that are regenerating freely" and growing on "sheltered ridges and steep southerly and easterly slopes in wet and dry sclerophyll forest.". They assessed its conservation status as 2R (geographic range less than 100 km and rare) and noted that "Although not specifically protected, large populations occur in areas unlikely to be under immediate threat, and the species is not considered to be threatened in the short term".

Hill (2003) estimated the population size as > 10 000 mature plants and assessed its status as Least Concern, but provided no statement of how the estimates or conservation assessment were made. *Macrozamia johnsonii* is currently listed as

Endangered in Schedule 1 of the NSW *Threatened Species Conservation Act (1995)*, having been listed on Schedule 1 in 1995 with the commencement of the Act. This listing is not consistent with Hill's assessment, though the extent to which Hill included timber harvesting as a potential threat is uncertain, nor with with general observations suggesting a species which has remained locally abundant and freely regenerating for at least the last fifty years within forests that have had a long history of timber harvesting and frequent burning for grazing.

This paper quantitatively documents the distribution, population size and structure and habitat of the *Macrozamia johnsonii* population based on recent field surveys, and makes a detailed assessment of its conservation status using current IUCN guidelines and criteria, particularly in the context of timber harvesting,.

Methods

Plant data

Data on distribution and abundance were compiled from several sources (Table 1). Only the two systematic surveys, described further below, consistently included counts of plants in plots of known area, although some other data included approximate estimates of local population size and extent. Data from the Forests NSW Flora and Fauna data base and the NSW NPWS Atlas were screened to exclude records of low locational accuracy. Where accuracy was not stated, records were regarded as unreliable, and excluded, if location descriptions were too vague to determine the location to within 500 m, or if there was a > 500 m discrepancy between the location description and the associated grid reference. Excluding such records, all sources combined provided 287 separate locations at which the species was recorded. Known distribution extent of *Macrozamia johnsonii* was derived by generating a minimum convex polygon which included the 287 records. All records at the vertices of the polygon were accurate to within 100 m.

Two surveys were conducted to obtain quantitative data on *Macrozamia johnsonii* density and distribution. Firstly, within an area of approximately 15 000 ha, defined by Crown Lands within the minimum convex polygon containing the known limits of distributional extent based on previous records, plots were sampled using simple random selection. Secondly, within an area occupying approximately 340 ha of Chaelundi National Park, considered to support consistently relatively dense stands of *Macrozamia johnsonii*, a square grid of 250 m resolution was superimposed on the area and each grid square sampled by a single randomly placed plot. The second survey area was entirely contained within the perimeter of the first area, but the two sample areas did not overlap. In both areas, at each sample point the numbers of *Macrozamia johnsonii* plants were counted in each of three size categories: mature, immature and seedling, within either a 10m or 20m radius. Plants with an evident above-ground caudex were counted as mature plants, on the basis that plants without a caudex were very rarely observed to have produced cones. Seedlings were the smallest size class, arbitrarily defined as plants with fewer than 10 leaves. All plants intermediate in size between the seedling class and the mature class were counted as immature. The choice of 10 or 20 m sample radius was determined in the field for individual plots, based on the stand density and homogeneity.

Table 1. Characteristics of data sources for records of *Macrozamia johnsonii*.

Number of records is the number of separate locations at which *Macrozamia johnsonii* was recorded. Number of plots is the number of sample plots, including those at which *Macrozamia johnsonii* was not recorded.

Data source	Description	Record dates	Number of records	Number of plots
NSW Wildlife Atlas	Compilation of records from various sources, obtained from former NSW National Parks and Wildlife Service and not otherwise listed in this table	1952–1998	12	-
FNSW Flora and Fauna Data Base	Records of *Macrozamia johnsonii* from threatened species target survey for pre-harvest assessment, plus locations recorded incidentally during other surveys	Dec 1998–Jul 2005	173	-
FNSW systematic flora survey	Randomly located 0.1 ha plots occurring within area subsequently defined as extent of *Macrozamia johnsonii* occurrence	Jan 1991–Oct 1993	4	12
Macrozamia johnsonii systematic survey, sample area 1	Plots randomly located on Crown Land, within known distributional extent of *Macrozamia johnsonii*	Oct 2004–Jul 2005	38	53
Macrozamia johnsonii systematic survey, sample area 2	Plots randomly located within area of apparent high population density within Chaelundi National Park	May–June 2005	60	108

Stands of high density, which were judged to be of relatively homogeneous density regardless of the choice of distance, were sampled with a 10 m radius, to save time in counting large numbers of plants. All other stands were sampled using 20 m radius.

Environmental data

The environmental variables were obtained from a 25m Digital Elevation Model or from other GIS models developed during a NSW Regional Comprehensive Regional Assessment process. The variables used (Table 2) are described more fully in NSW NPWS (1994).

Analysis of habitat

To reduce potential bias, only data from surveys that used randomly located sample plots were used for analyses of environmental relationships and for estimates of population size. All randomly located plots within the minimum convex polygon defined as described above, including all those in which *Macrozamia johnsonii* was not recorded, were used for these purposes. These data were derived from the last three sources listed in Table 1. The occurrence of *Macrozamia johnsonii* in relation to environmental factors was investigated using generalised linear models (GLM, McCullagh and Nelder 1989) and tree models (Crawley 2003). For the former, the response variable used was binary (presence or absence of mature *Macrozamia johnsonii*), and a binomial link function was used. A full model was initially fitted using all environmental variables and then each variable deleted in turn. The effect of deletions was judged on the basis of the Akaike information criterion (AIC, Burnham & Anderson 2002). Variables for which deletion caused a stepwise reduction in AIC were progressively removed to give a final model. Two response variables were used in separate analyses for the tree models: 1. raw count data of mature plants only, with plots in which only immature or seedling plants were recorded being included as counts of zero; and 2. a binary (presence/absence of mature plants) response as for the GLM models. Analyses were performed using the 'glm', 'tree' and associated functions in S-Plus 4.5.

Table 2. Environmental variables used in analysis

Factor	Units	Comments
aspect to north	degrees	calculated as azimuth if ≤180° or (360–azimuth) if >180°
moisture index	index between 0 and 100	index derived from rainfall, evaporation, radiation and soil depth
slope	degrees	calculated from 25m, filled DEM
mean daily solar radiation during January	MJ m^{-2} d^{-1}	
mean daily solar radiation during July	MJ m^{-2} d^{-1}	
topographic position	index between 0 and 100	relative position, 0=gully to 100=ridge crest

Estimates of population size

A frequency histogram of the count data showed that the counts do not conform to any of the commonly used parametric probability distributions (normal, lognormal, poisson, exponential or negative binomial). In particular, the data had substantially higher tail frequencies than expected for contagious distributions such as negative binomial (Douglas 1979). As a result, mean densities (mean number of plants per 20 m radius plot) were obtained using a bootstrap mean (with 100 000 runs) and confidence limits were estimated using the BCa percentiles (Crawley 2003). Analyses were conducted using the bootstrap function in S-Plus 4.5. Four types of population estimates (mean and lower 95% confidence limit 2.5% percentile) were compared:

1. Mean density was estimated using all plots, including zero counts. The density estimates were multiplied by the total area of the sampled distribution extent to obtain estimates of total population size. Estimates for the high density area (systematic survey number 2), which was sampled at higher intensity, were obtained separately from the remaining area within the minimum convex polygon, and the two subtotals combined.

2. Mean density was estimated only from plots where *Macrozamia johnsonii* was recorded, and the proportion of non-zero records used to estimate the proportion of the sample area on which *Macrozamia johnsonii* is expected to occur, assuming that the probability of occurrence follows a binomial distribution and is equal throughout each of the sample areas. As for the previous estimates, the two sample areas were treated separately.

3. A refined version of method two, where the proportion of each sampled area occupied by *Macrozamia johnsonii* was estimated using probabilities of occurrence in each 25 m square grid cell. The probabilities were obtained using parameter estimates from the final GLM habitat model and the values of the relevant environmental variables in each grid cell.

4. Based on mean counts in environmental classes obtained from the regression tree models based on count data. Mean counts were estimated for each 25 m grid cell based on the environmental thresholds provided by the model. No attempt was made to estimate confidence limits in this case.

Assessment of conservation status

Assessment is made in relation to the criteria described in IUCN (2001), interpreted using the associated guidelines (Standards and Partitions Working Group 2006). For criteria where we do not have quantitative data from which to estimate parameter values, we have considered what we believe to be a plausible range of values based on available circumstantial evidence. This corresponds to the categories of lowest quality information in the IUCN guidelines, used to 'infer' or 'suspect' taxon characteristics relative to threshold values. In these cases, we have attempted to use a precautionary but realistic attitude to risk, as suggested in the guidelines.

Results

Habitat

The area in which *Macrozamia johnsonii* occurs comprises an intergrading mosaic of grassy open eucalypt forest and shrubby wet sclerophyll forest, with patches of rainforest in the most sheltered sites. Common canopy dominants include *Corymbia variegata*, *Eucalyptus microcorys*, *Eucalyptus biturbinata*, *Eucalyptus carnea*, *Eucalyptus siderophloia* and *Lophostemon confertus*. Based on the GLM model, the factors that most strongly influenced the occurrence of *Macrozamia johnsonii* were moisture index and slope. *Macrozamia johnsonii* is much more likely to be found on sites with high moisture index ($p<<0.001$) and steep slopes ($p=0.007$). The addition of any of the other variables was found to not significantly affect the model which included these two variables, although some were significant on their own due to correlations among some variables. This result was consistent with the tree model derived from binary data, for which the major split was moisture index > 81.5 and other major splits were on slope. However, for the wettest sites, topographic position was also important in the tree model, with *Macrozamia johnsonii* being most likely to occur on lower slopes. For the count data, the major split was on solar radiation, with the stands of highest density found on the more sheltered sites, but subsidiary splits were based on moisture index and slope as for binary data.

Population size and extent

The minimum convex polygon enclosing all records (extent of occurrence) covers 22 200 ha. IUCN guidelines suggest that area of occupancy should be estimated at a scale appropriate to the relevant biological aspects of the taxon being considered. In the case of *Macrozamia johnsonii*, the scale of sample plots (20 m radius) could be considered appropriate as it is well within the range of short-term genetic exchange and short-term seed dispersal. On this basis and using the proportion of plots occupied by mature individuals, the extent of occurrence of 22 200 ha is equivalent to an area of occupancy of 10 100 ha. This represents an extreme minimum estimate relative to IUCN guidelines, which indicate that a scale of 1–4 km^2 is appropriate for many species. The population estimate from each of the four methods (Table 3) is approximately 3.5 million mature plants, equivalent to a density of about 158 plants per ha. The highest density recorded was 228 mature plants in a 20 m radius plot.

Population structure

There is a strong correlation between the density of mature plants and that of immature plants and seedlings (Spearman Rank correlation $p<<0.01$ in each case). The density of immature plants in each plot (bootstrap mean = 48.2, 95% BCa limits = 36.8 to 62.9) is not significantly different to that of mature plants, but seedling density is significantly greater than either (mean = 122.8, 95% BCa = 79.8 to 207). There

Table 3. Estimates of population size, of total number of mature plants

Methods are numbered as described in the text. Sample areas 1 and 2 refer to the general and high density areas respectively. Plots are 20 m radius (0.126 ha).

Method	Sample area	Effective area (ha)		Density (plants per plot)		Population estimate	
		Mean	Lower 2.5 percentile	Mean	Lower 2.5 percentile	Mean	Lower 2.5 percentile
1. Overall mean, all plots	1	21860	-	19.5	13.6	3.39×10^6	2.36×10^6
	2	340	-	30.1	16.0	81400	43300
	Total					3.47×10^6	2.40×10^6
2. Non-zero mean x proportion	1	9520	7650	44.7	32.9	3.39×10^6	2.00×10^6
	2	170	120	61.3	38.6	814 00	37600
	Total					3.47×10^6	2.04×10^6
3. GLM	Total	9038	6099	50.6	38.6	3.64×10^6	1.87×10^6
4. Tree model on counts	Total	-	-	-	-	3.63×10^6	-

were three plots with only mature plants present, with a single plant in each case. There were 24 plots with immature or seedling plants but no mature plants. If it is assumed, as seems reasonable, that mature plants represent at least as long a time interval as non-mature plants, then the proportion of plots with only non-mature plants is significantly higher than expected by chance. The mean density of plants in plots which contained only non-mature individuals was 8.2 plants per plot (95% CI = 5.3–15.9). This is substantially and significantly lower than the mean for non-mature individuals for all plots combined (mean = 150, CI = 104–223).

Distribution by land tenure

The distribution extent includes National Park reserve, State forest used for timber harvest and private land. Since all systematic sampling has been in the former two tenures, relatively little is known of the occurrence of *Macrozamia johnsonii* on private land. However, based on estimates of effective habitat area (i.e. summed probabilities of occurrence) from the GLM model, and assuming mean plant density is the same for all tenures, approximately 59% of the total population occurs in State forest, 30% in National Park and 11% on private land. Using mean plant density by tenure, the proportion of the population in National Park is 31%. The private land includes some cleared areas, especially on flatter areas in the main river valley, but these are also areas of very low predicted probability of occurrence of *Macrozamia johnsonii* so are assumed to not substantially affect the estimates.

General field observations

Although no systematic data were collected, most of the stands sampled during recent surveys were observed to have been recently burnt (within the previous 3–5 years) and some casual observations were made, both within sample plots and of plants observed while traversing other stands. As a conservative estimate, several tens of thousands of live plants were seen during surveys. Almost all mature plants in recently burnt areas had charred leaf bases but had well-developed crowns of live fronds which in many cases appeared to have regrown following fire. Approximately 15 dead individuals, or remains, were seen. Time since death is unknown, but most appeared to have died within the previous 2–3 years. For three plants, death could be confidently attributed to direct effects of fire. In all three cases, individuals had relatively tall trunks (at least 1 m long) and fire had burnt completely through the vascular cortex at the base of the trunk. A few other plants had fallen trunks, but it was not certain that these were killed by the fire or had been subsequently burnt. Other plants were crushed under fallen trees and were probably indirect casualties of fire, although in a few cases crushed plants had survived. In any case, it seems that the natural mortality rate for mature plants from all causes is very low. Plants with cones were observed to be scattered through the population in various stages of cone development. Although no quantitative data were collected, there was no evident synchrony of cone development with the occurrence of the recent fire.

Discussion

Population size and structure

The high proportion of non-mature plants (about 80% of the population) across both non-mature size classes suggests that the species is regenerating freely and has done so in the recent past. This provides some quantitative evidence to support previous observations of this nature. The significantly higher proportion of plots with only non-mature plants, compared to those with only mature plants, along with the lower density in the former, is indicative of local-scale recruitment into areas not previously occupied by *Macrozamia johnsonii* within the last few decades. This suggests that the population currently may be expanding. The alternative scenario is a declining adult population, on the basis that mature individuals have been lost from sites where they are currently absent and that the species relies on a juvenile plant bank for recruitment, with a high turnover of juveniles and slow recruitment into the mature population. This alternative is very unlikely. Dead mature plants leave distinct cavities in the soil surface following decomposition of the caudex. It is reasonable to expect that these would be evident for considerable time, until obliterated by soil movement. Very few such cavities were observed. Also, non-mature plants comprised a full range of sizes between class size limits. This is not consistent with a juvenile plant bank with high turnover, which would be expected to comprise mainly small plants. If the population is expanding as suspected, the most likely explanation is the change in fire regimes over the last few decades. There is strong anecdotal evidence that frequency of deliberate fires has declined during this time. As discussed further below, frequent fire may prevent or slow new recruitment. Increasing the fire interval will thus provide more opportunities for new recruitment and potentially lead to an expanding population in the longer term.

Potentially adverse disturbances and main threats

General threats to cycads have been identified as small population size, land clearing, selective eradication, harvesting of plants and seeds, loss of genetic variation, loss of pollination mutualisms, drought, fire and timber harvesting (Donaldson 2003). *Macrozamia johnsonii* has a relatively very large population for a threatened cycad, so population size is not a conceivable threat to this species. The other factors are considered below.

Clearing

Past clearing in the area where *Macrozamia johnsonii* occurs has been restricted mainly to the river valley and has been limited elsewhere due to the steepness and relative inaccessibility of most of the area. Currently, most (about 90%) of the uncleared habitat is on public land, not subject to clearing. The remaining 10%, on private land, is potentially subject to clearing, but due to the topographic and other constraints that prevented earlier clearing, it is very unlikely that any further clearing will occur in the area without very substantial changes in the economic context for pastoralism.

Eradication and harvesting

In Australia, cycads are recognised as being poisonous to domestic stock and have sometimes been the targets of specific attempts at eradication. The extent to which this has occurred for *Macrozamia johnsonii* is unknown, but it is unlikely to have been significant, because the area in which the species occurs has been used historically for extensive rough grazing, with low stocking rates, and it is unlikely that the intensive labour required for systematic eradication would be compensated by increased commercial return on anything other than a very small scale.

The extent of illegal collection is unknown. Due to the large size of mature plants, and the steepness and relative inaccessibility of most of the habitat, it is very unlikely that significant numbers of mature plants would be taken. Some seeds and small plants may be taken, but the abundance of seedlings in the population make it unlikely that this would significantly affect ongoing recruitment.

Fire

Field observations described above show that mature plants and larger seedlings are resilient to a single fire, an observation consistent with the behaviour of other Australian cycad species. Even seedlings with only 2–3 leaves were observed to re-sprout after low intensity fire. However, since cycads do not accumulate a soil-stored seed bank for more than a few years, repeated fire at short intervals (less than 1–3 years) may prevent or impede recruitment, even though it has little or no effect on larger plants. Ornduff (1990) suggests that lack of fire may suppress recruitment, due to shading and competition from mature plants, but the abundance of seedlings observed under mature canopies in unburnt stands suggests that shading and competition is unlikely to suppress recruitment for *Macrozamia johnsonii*. Over long periods, repeated higher-intensity burning may eventually breach the otherwise fire resistant trunk of mature plants and may be the most common cause of natural mortality. However, based on field observations noted above, the mortality rate is inferred to be very low. There may also be positive aspects of fire. There is some evidence that fire stimulates cone production in related species (e.g. *Macrozamia communis*, Ballardie & Whelan 1986). No data are available for *Macrozamia johnsonii*, but casual observations described above suggest that it may not be as responsive as other species.

Timber harvesting

Timber harvesting changes the structure of the forest habitat and physically damages some plants, the proportion of both depending on the intensity of the logging operation. The immediate impact of timber harvesting is thus to reduce the size of *Macrozamia johnsonii* populations. In the longer term, populations may increase or decrease, depending on the extent to which the changed vegetation structure facilitates or impedes recruitment, and the extent to which surviving plants respond to release from competition. There are no data on the longer term impact of logging, but in a qualitative sense, *Macrozamia johnsonii* is common in areas which have been subject to repeated logging over a period of at least 50 years. In NSW State forests in the area concerned, timber harvesting is currently selective and impacts are minimised by a range of legislated and other harvesting constraints. Although there are no quantitative data available on the response of *Macrozamia johnsonii* to physical damage by timber harvest, casual observations suggest that individual plants are fairly resilient and generally survive, although plants are killed if the trunk is severed, the plant is uprooted or the growing point destroyed. About 30% of the gross area of State forest in the area is available for harvesting (R. Kirwood, FNSW Resources Officer, *pers. comm. 2007*), the remainder being reserved for management exclusion zones or inaccessible due to topographic constraints.

Other factors

Individual populations of *Macrozamia johnsonii* occur in close geographic proximity, with no known disjunct outliers, and the species is regenerating freely. These factors make it unlikely that loss of genetic variation will be a significant threat to the species. Loss of pollination mutualisms is also unlikely to be a threat, in view of the abundance of seedlings and the relatively unmodified state of much of the habitat. Based on recent observations, *Macrozamia johnsonii* appears tolerant of drought.

Assessment against IUCN criteria

The following section describes the evaluation of the species against the IUCN criteria using the population estimates reported in this study together with consideration of plausible bounds for parameter values for which no quantitative data are available.

Criterion A. Reduction in population size.

Macrozamia johnsonii still occurs within the vicinity of all previous records of reliable locational accuracy. Although in most cases the accuracy of historical records is inadequate to assess whether particular stands have persisted, there is no evidence to suggest significant historical decline. The only potential threat which may reduce populations in the short to medium term is timber harvesting. Although there are no quantitative data which allow direct estimation of the impact of timber harvesting, the likely impacts may be assessed from consideration of effects on effective habitat area, as follows. As noted above, it is estimated that 30% of the State forest area is, or will be, harvested. All private land is included as net harvestable. Although this will overestimate the area affected, it at least compensates for the unknown but potentially higher harvest intensity on private land. On this basis, assuming (as described above) that 59% of the total effective habitat area is in State forest and 11% is on private land, approximately 29% (30% x 59% + 11%) of the effective area of habitat of the species is potentially subject to timber harvest. At the fine scale (metres to tens of metres), selective logging results in a mosaic of patches of different degrees of disturbance, including undisturbed patches, but there are few data on the extent of such patches following logging in the study area. Preliminary data (D. Binns, unpubl. data) from one area suggests that about 15% of the net area is affected by disturbance sufficiently severe to potentially cause mortality of *Macrozamia johnsonii*. It is very unlikely that the area so affected would exceed 30%, which represents a plausible, but extreme, upper limit for estimating annual mortality due to logging. Logging in this area is currently planned on a cutting cycle which varies from 10 to 30 years, but is conservatively assumed to average 15 years, which implies an average annual mortality of 1% (15% spread over 15 years) as a best estimate, and 2% (30% over 15 years) as an upper bound. Burgman *et al* (2001) suggest a simple formula for estimating habitat loss for stochastic events, for species which do not require periodic disturbance for recruitment. This formula is: $S = (1-p)^n$, where S is the proportion of habitat which is suitable to support mature plants, p is the annual probability of disturbance and n is the time (years) required for newly-disturbed habitat to support mature plants. To estimate n, it is necessary to estimate age at first breeding. Cultivated plants have been observed to produce cones after 15 years, but wild plants may take longer. Johnson (1961) notes that "massive plants 2 m tall have been grown from seed in less than 100 years". It is unclear whether this refers to the trunk only, or trunk and crown, but the use of the term "massive" implies substantial trunk development. Since wild plants with only a very short trunk may produce cones, we suggest a plausible range for the age at first breeding is 20–40 years. Using the formula, with annual mortality of 1% and time to maturity of 20 years, the estimate of the proportion of long-term suitable habitat is 82%. This infers a long-term population reduction of 18% within the area subject to logging and 5% (18% x 29%) over the whole population. If the annual mortality is 2% and the effective age at first breeding is 40 years (either because the age at maturity is higher than expected, or because recruitment is initially impeded in disturbed areas) then the inferred long-term population reduction is 45% within the net logging area and 13% overall. The latter represents the worst-case extreme of plausible scenarios, but is still below the Vulnerable category threshold of Criterion A3. These estimates would be higher if recruitment was impeded to a greater extent than expected in disturbed areas, or lower if disturbance facilitated recruitment or promoted growth of surviving plants through removal of competition.

Criterion B. Geographic range (extent of occurrence or area of occupancy)

The estimated extent of occurrence of 220 km^2 and area of occupancy of approximately 100 km^2 are both below the thresholds for the Endangered and Vulnerable categories, so *Macrozamia johnsonii* meets the primary criterion for these categories. With respect to secondary criterion 'a', since the most serious potential threat (logging) creates a disturbance mosaic in logged areas and does not '..rapidly affect all individuals..' (under the definition of 'location', IUCN 2001), we do not regard it as a plausible threat in the context of this criterion. As argued above, there is also no other plausible threat which affects this species in the short term. On this basis, *Macrozamia johnsonii* cannot be assessed in relation to secondary criterion 'a'. Criterion 'b (v)' is met based on the logging impact scenario described above. With respect to criterion 'c', this is a long-lived species with very low natural mortality and long generation time. Even moderate fluctuations are very unlikely, so this criterion is not met. Thus, the species meets at most one of the required two secondary criteria, so Criterion B is not met.

Criterion C. Population size

The lower 2.5 percentile of population size is estimated in this study to be at least 1.87 million mature individuals using the most conservative estimate of the four methods. Since the species is dioecious, and if it is assumed that the sex ratio is even, the effective population size in the context of this criterion is about 0.9 million. This vastly exceeds the maximum threshold for the Vulnerable (10 000) and more threatened categories, so *Macrozamia johnsonii* clearly does not meet this primary criterion for any threatened category.

Criterion D. Very small or restricted population

The population size (> 0.9 million) and area of occupancy (> 100 km^2) exceed the threshold for this criterion under the Vulnerable and more threatened categories. The species cannot be assessed in relation to the number of locations, as noted above under Criterion B. *Macrozamia johnsonii* does not meet this criterion.

Criterion E. Probability of extinction based on quantitative analysis

A detailed population viability analysis is not possible with the existing data for this species. However, a protocol developed by Burgman *et al.* (2001) allows a relative assessment of risk of extinction using the available data. For the purpose of using this protocol, we have assumed that the species lives for 200 years and is naturally fairly resilient, both plausible characteristics for the species, which gives a value of 500 for parameter F using the table provided by Burgman *et al.* (2001). The average density (D) is estimated as 0.025 ha per plant, based on the lower 2.5 percentile mature population of 0.9 million over a total area of 22200 ha of habitat. These parameters provide a target area for protection of D*F = 12 ha. This is the area required, in the absence of threatening processes, to ensure that the risk of the species declining to less than 50 individuals ("pseudo-extinction") is no more than 0.1% over 50 years. This is intended to be used as a relative measure to rank species of concern with respect to other species, but does not indicate that this is the actual area necessary. However, since the area of *Macrozamia johnsonii* habitat (> 6000 ha) in formally reserved National Park exceeds the minimum estimate by more than two orders of magnitude, using this protocol *Macrozamia johnsonii* is rated as a species with relatively extremely low extinction risk.

Overall assessment

Macrozamia johnsonii does not meet any of the IUCN criteria for any of the threatened categories, and is most appropriately assessed in the category of Least Concern. The values of some parameters used for assessment are based on circumstantial evidence and informed opinion rather than quantitative data. We believe we have taken a realistic attitude to defining plausible bounds for these parameter values, but it is possible that some values may be found to be outside this range when quantitative data become available. In that case, the assessment would need to be reviewed. The current assessment is most sensitive in respect of the population decline criterion. If other, currently unrecognised, significant threats develop (for example, if the species was found to be highly susceptible to longer term climate change or a pathogen), it is possible that the species may meet the threshold for the Vulnerable category. However, based on present information, *Macrozamia johnsonii* fails to meet any of the criteria for listing as a threatened species. Its current listing on Schedule 1 as an Endangered species under the NSW *Threatened Species Conservation Act (1995)* is therefore not considered appropriate.

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A broad typology of dry rainforests on the western slopes of New South Wales

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Abstract: Dry rainforests are those communities that have floristic and structural affinities to mesic rainforests and occur in parts of eastern and northern Australia where rainfall is comparatively low and often highly seasonal. The dry rainforests of the western slopes of New South Wales are poorly-understood compared to other dry rainforests in Australia, due to a lack of regional scale studies. This paper attempts to redress this by deriving a broad floristic and structural typology for this vegetation type. Phytogeographical analysis followed full floristic surveys conducted on 400 m^2 plots located within dry rainforest across the western slopes of NSW. Cluster analysis and ordination of 208 plots identified six floristic groups. Unlike in some other regional studies of dry rainforest these groups were readily assigned to Webb structural types, based on leaf size classes, leaf retention classes and canopy height. Five community types were described using both floristic and structural data: 1) *Ficus rubiginosa–Notelaea microcarpa* notophyll vine thicket, 2) *Ficus rubiginosa–Alectryon subcinereus–Notelaea microcarpa* notophyll vine forest, 3) *Elaeodendron australe–Notelaea microcarpa–Geijera parviflora* notophyll vine thicket, 4) *Notelaea microcarpa–Geijera parviflora–Ehretia membranifolia* semi-evergreen vine thicket, and 5) *Cadellia pentastylis* low microphyll vine forest. Floristic groupings were consistent with those described by previous quantitative studies which examined smaller portions of this study area. There was also general agreement between the present analytical study and a previous intuitive classification of dry rainforest vegetation throughout the study area, but little concurrence with a continental scale floristic classification of rainforest.

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Introduction

Dry rainforest refers to those communities that have floristic and structural affinities to mesic rainforests (Floyd 1990), and occur in parts of eastern and northern Australia where rainfall is comparatively low and highly seasonal (Gillison 1987; McDonald 1996). Dry rainforest communities in inland Queensland were recorded in the 19th century when the explorer Thomas Mitchell observed bottle tree (*Brachychiton* spp.) scrubs (Mitchell 1848). Dry rainforest was well known to the Gamilaraay people of northern NSW; evident from numerous references, in Aboriginal oral history of the Gunnedah area, to the occurrence of 'hop-vine scrub' in locations which currently support dry rainforest (O'Rourke 2005; Curran 2006). However, it was not until the 1960s, during a CSIRO investigation of the land systems of the Hunter Valley (Story 1963a; 1963b), that dry rainforests were formally documented on the western slopes of NSW 'non-eucalyptus [sic] trees and shrubs in closed communities are common on rocky hilltops and in ravines' (Story 1963b; p. 27). A later study focused on the vine thicket vegetation at Brushy Hill Range, near Scone (Turner 1976), which was considered to support the largest stands of such vegetation in the upper Hunter Valley. From 1967 onwards, John B. Williams of the Department of Botany, University of New England, Armidale, undertook many inspections of patches of dry rainforest (mainly semi-evergreen vine thicket – SEVT) on the North Western Slopes of NSW (J.B. Williams, unpub. data; Williams & Guymer 1977; Williams 1983). His work, following on from Baur (1957; 1965) and Webb's (1959; 1968) work at state and continental scales, culminated in an increased awareness of dry rainforest on the North Western Slopes (Holmes 1979; Beadle 1981; Benson 1983; Pulsford 1983; 1984). Hereafter reference to dry rainforest on the North Western Slopes is used in a general sense: it also refers to stands in adjacent botanical subdivisions such as the eastern parts of the North Western Plains and the spur of Northern Tablelands that comprises the Nandewar Range.

Beadle (1981, p. 181) recognised two types of dry rainforest on the North Western Slopes of NSW: *Cadellia pentastylis* Alliance and Mixed Stands. These two types broadly equated to the low microphyll vine forest (LMVF) and SEVT structural types of Webb (1968; 1978), respectively. Data from some stands of dry rainforest of the western slopes of

NSW (J.B. Williams unpub. data) were included in a floristic classification of Australian rainforests based on numerical analysis of species distributions (Webb & Tracey 1981; Webb et al. 1984). These stands were grouped into the C_2 ecofloristic province, which represented patches of rainforest that occur in a sub–humid warm subtropical climate (Webb et al. 1984). Most stands in this group occur in southern and central Queensland, but it includes stands from northern NSW (Webb et al. 1984).

In the 1980s, Australian governments initiated the National Rainforests Conservation Program, which fostered renewed interest in rainforests throughout Australia. During the 1980s and 1990s there were several important studies of the dry rainforests of western NSW. Floyd (1987) examined the conservation status of rainforest in northern NSW, and subsequently broadened this work to classify rainforests throughout NSW, including the western slopes (Floyd 1990). The rainforests of NSW were delineated into four structural subformations (subtropical, dry, warm temperate, and cool temperate; *sensu* Baur 1957) and then intuitively classified into 13 alliances and 57 suballiances on the basis of floristics (Floyd 1990). Additionally, two groups of suballiances were described based on structure rather than assigned to a floristic alliance. One of these, the microphyll vine thicket group, which was placed in the dry rainforest subformation, included suballiances No. 31 *Alectryon forsythii–Alectryon subdentatus–Notelaea microcarpa* and No. 32 *Notelaea microcarpa–Ehretia membranifolia–Geijera parviflora*. Suballiance No. 31 is found in the deeply dissected Guy Fawkes–Macleay Gorges on the eastern edge of the Great Dividing Range in northern NSW (Floyd 1990), although communities similar to this suballiance, dominated by *Ficus rubiginosa–Alectryon forsythii–Notelaea microcarpa*, are found in the Melville Ranges south-west of Tamworth (Banks 2001) and hills near Tamworth (Hosking 1990). Suballiance No. 32 is found on the western slopes of NSW and was equated to SEVT (Floyd 1990). This suballiance includes: (1) SEVT communities (*sensu* Webb et al. 1984) that occur on basalt-derived soils and which are dominated (in addition to those species that describe the suballiance) by *Pouteria cotinifolia* var. *pubescens* and *Elaeodendron australe* var. *integrifolia*; (2) communities which occur on sandstone and which are dominated by *Cadellia pentastylis*; and (3) communities from the upper Hunter Valley which occur on several substrates and which are co-dominated by species such as *Ficus rubiginosa* and *Melia azedarach*.

Subsequent floristic surveys have examined these community types of Floyd's (1990) suballiance No. 32. *Cadellia pentastylis* stands throughout NSW were surveyed by Benson (1993) and found to be variable in their floristic composition, but generally restricted to lithic sandstone or conglomerate substrates. Curran and Curran (2005),

Table 1. Summary of results of studies which described dry rainforest communities on the western slopes on NSW based on numerical analysis of floristic data.

# Results presented are those undertaken using an unweighted pair-group arithmetic averaging (UPGMA) clustering strategy. Cluster analysis using TWINSPAN (two-way indicator species analysis) produced slightly different results.

Study	**Dry rainforest communities described**
McDonald 1996#	*Cadellia pentastylis* community
	SEVT, stands from northern NSW and the upper Hunter Valley
DLWC 2002	Dry Rainforest of gorges and gullies of the Nandewar Ranges
	Communities dominated by *Cadellia pentastylis* on sandstone
	SEVT on basalt hills
	'Dry Scrubs' on volcanic substrates. This community is a shrubby eucalypt woodland, with scattered dry rainforest species throughout, which in some places coalesce to form small stands of vine thicket
DEC 2004a	SEVT on a variety of substrates
	Cadellia pentastylis forest on sediments
	Rusty Fig Dry Rainforest, which occurs on steep rocky sites predominantly in the southern part of the Bioregion, such as the Melville Range
	Alectryon/Rusty Fig/Mock Olive Dry Rainforest, which occurs on steep slopes, such as the gorges of the Nandewar Ranges
Peake 2006	Hunter Valley Vine Thicket
	Upper Hunter Depauperate Dry Rainforest
	Lower Hunter Dry Rainforest
	Upper Hunter Narrabeen Gully Ironwood Dry Rainforest

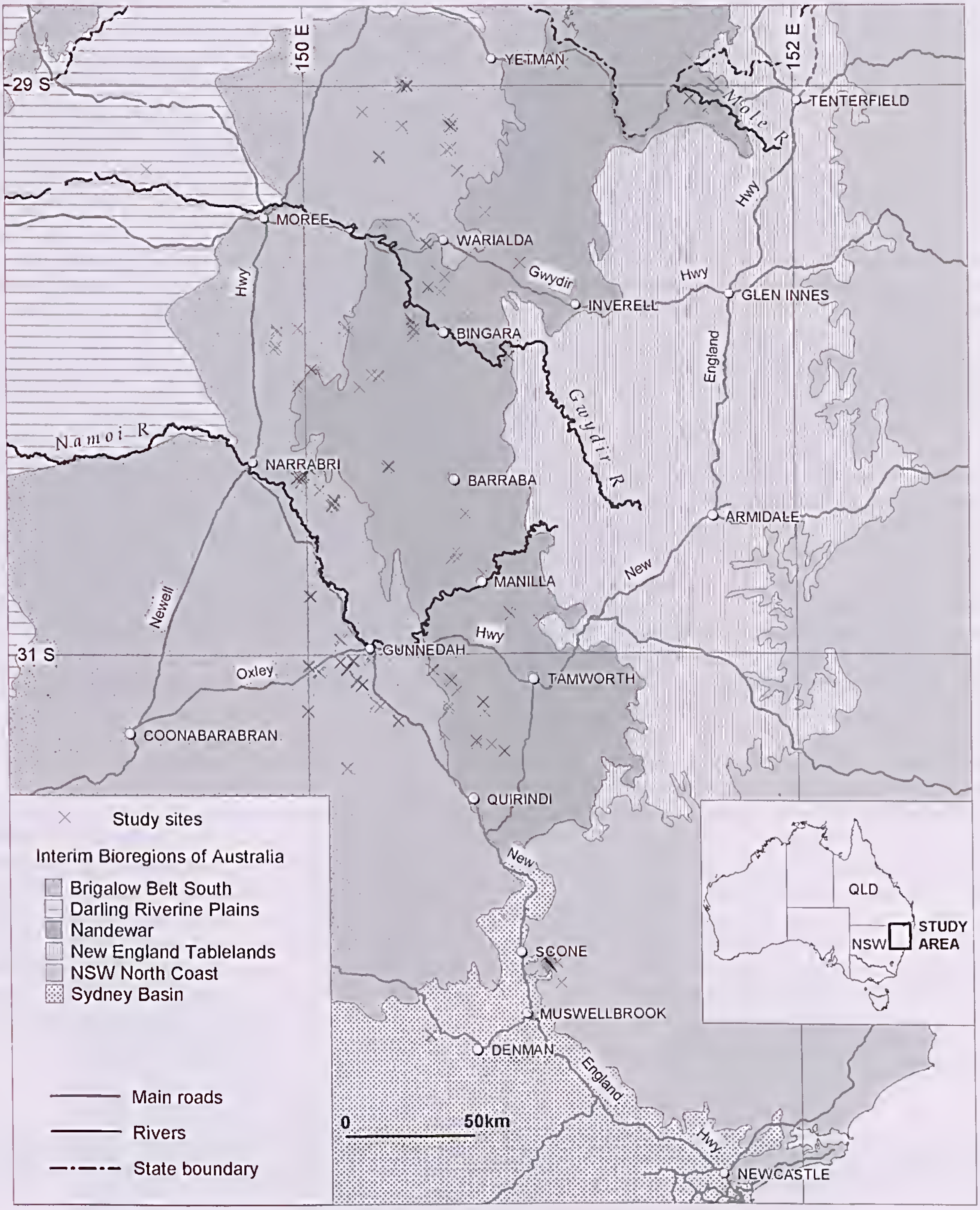


Fig. 1. Location of survey sites and Interim Bioregions of Australia (Version 6.1 © 2004 Department of Environment and Heritage). Base Map data © 2004 Geosciences Australia.

who reported on several stands of *Cadellia pentastylis* not surveyed by Benson (1993), further demonstrated the high fidelity of this community for sandstone or conglomerate lithology, although one stand does occur on acid volcanics. The floristic composition of SEVT at Derra Derra Ridge, a large stand near Bingara, in northern NSW, was shown to be analogous to stands further north in NSW and has similar preferences for basalt-derived loam soils (Benson et al. 1996). A community on granite at Kwiambal National Park near Ashford in northern NSW was equated by Hunter et al. (1999) with the Mixed Stands of the Beadle (1981) typology. However, it would more correctly be described as a dry sclerophyll woodland with some dry rainforest species, as it lacks the richness of dry rainforest species and occasional closed canopy structure needed to class it as either Mixed Stand or SEVT.

Four studies have used numerical classification methods to delineate different types of dry rainforest on the western slopes of NSW (Table 1). The first of these (McDonald 1996) used species lists (J.B. Williams unpub. data; Floyd 1990; Benson 1993) from eight dry rainforest stands in NSW to analyse the floristic composition of vine thicket of the entire Brigalow Belt Bioregion (*sensu* Thackway and Cresswell 1995), including floristic sites from Queensland. The second study (DLWC 2002) mapped vegetation on four 1:100 000 scale map sheets in northern NSW, based on aerial photograph interpretation and analysis of quantitative floristic data from 20 x 20 m quadrats. The third study (DEC 2004a) modelled vegetation across the Nandewar Bioregion of NSW based on quantitative plot data, including some collected for this paper. There was considerable concurrence in the dry rainforest communities identified by these three studies (Table 1). Each of these three studies identified separate SEVT and *Cadellia pentastylis* communities, and a dry rainforest community which occurs in gorges and gullies of the Nandewar Ranges was reported for the two studies that sampled plots from that area (DLWC 2002; DEC 2004a). A fourth study, which focused on the central Hunter Valley (Peake 2006), identified four types of dry rainforest in that study area (Table 1). One of these, Hunter Valley Vine Thicket, included stands at Brushy Hill, near Scone, which were described in Suballiance No. 32 by Floyd (1990).

A recent statewide synthesis of quantitative floristic data (Keith 2004) described 99 vegetation classes, groups of vegetation defined mainly by floristic similarities, throughout NSW. Nine classes of rainforest were identified. Two of these classes occur on the western slopes of NSW: Dry Rainforest, which was described from data from DLWC (2002) and Western Vine Thickets as described by Benson et al. (1996) and DLWC (2002). The Western Vine Thickets class included both SEVT and *Cadellia pentastylis* communities (Keith 2004).

The aim of this paper is to identify the main floristic and structural groups of dry rainforests on the western slopes of NSW and to relate these groups and dry rainforest vegetation of the western slopes as a whole to existing NSW and Australian rainforest typologies.

Firstly, this will entail classifying floristic data using numerical methods. Based on previous numerical studies of dry rainforest on the western slopes, it is expected that four types of dry rainforest would be identified: SEVT (including vine thickets from the upper Hunter Valley); a *Cadellia pentastylis*-dominated community; a dry rainforest community that occurs in gorges and gullies of the Nandewar Ranges; and a dry rainforest community that occurs on steep rocky slopes, predominantly in the southern part of the Nandewar Bioregion. Secondly, the diagnostic species of the floristic groups and dry rainforest vegetation as a whole will be compared with those of continental (Webb et al. 1984) and state-wide (Floyd 1990) floristic typologies, and leaf size classes and canopy heights of floristic groups will be used to assign these groups to structural types (*sensu* Webb 1959; 1978).

Methods

Study area

The study area for this paper primarily comprises the western slopes and plains of New South Wales, north from the Liverpool Range to the Queensland border. This includes major towns such as Quirindi, Gunnedah, Tamworth, Manilla, Narrabri, Moree, Bingara and Warialda. There is also a disjunct part of the study area located in the upper Hunter Valley near the towns of Denman, Muswellbrook and Scone. The study area represents the region identified by Floyd (1990) as encompassing the distribution of dry rainforest on the western slopes of NSW.

Table 2. Summary of climatic data for weather stations in the study area. GUN = Gunnedah Soil Conservation Service, NAR = Narrabri Bowling Club, MOR = Moree Post Office, BIN = Bingara Post Office, BAR = Barraba Post Office, TAM = Tamworth Airport, SCO = Scone Soil Conservation Service. Source: Bureau of Meteorology (2004).

Variable	Weather station						
	GUN	NAR	MOR	BIN	BAR	TAM	SCO
Mean annual precipitation (mm)	636	643	579	744	689	673	650
Mean max. monthly temp. hottest month (Jan) °C	31.8	35.3	34.8	33.6	31.5	31.9	30.8
Mean min. monthly temp. coldest month (July) °C	4.6	3.4	3.4	2.2	0.2	2.9	4.6

The study area comprises parts of several NSW Botanical Subdivisions (Harden 1990) and Australian Bioregions (Thackway and Cresswell 1995; Figure 1). The majority of the study area is considered part of the North Western Slopes botanical subdivision, although the areas around Narrabri and Moree are in the North Western Plains subdivision and the Nandewar Range is in the Northern Tablelands subdivision (Harden 1990). The upper Hunter Valley is in the Central Western Slopes subdivision (Harden 1990), although some stands that were sampled were in the North Coast subdivision. The eastern part of the Brigalow Belt South (BBS) Bioregion (encompassing towns such as Gunnedah, Narrabri and Moree) forms the western part of the study area and the western part of the Nandewar (NAN) Bioregion (Tamworth, Manilla, Bingara) forms the eastern part of the study area (Figure 1). The upper Hunter Valley is located in the NSW North Coast (NNC) and Sydney Basin (SB) Bioregions (Thackway and Cresswell 1995).

The principle land uses in the study area are cropping (particularly in flatter areas of the BBS) and livestock grazing. Only a small proportion of the study area is located in conservation reserves (Benson 1999). The largest reserve in the northern part of the study area is Mt Kaputar National Park (36 800 ha; DEC 2004b), although there are several smaller reserves. In the upper Hunter Valley there are large reserves (Goulburn River National Park and Wollemi National Park) on the edge or just beyond the boundary of the study area, and only a few small reserves in the study area. The study area has been heavily modified since European settlement: 60% of the BBS and 66% of the NAN Bioregions (Benson 1999) and approximately 70% of the upper Hunter Valley (HCMT 2003) have been cleared.

Those parts of the study area that occur within the BBS Bioregion have a subtropical climate, according to the modified Köppen classification system used by the Bureau of Meteorology (2005), while the Nandewar Bioregion and the upper Hunter Valley have either subtropical or temperate climates, depending on elevation (Bureau of Meteorology 2005). Mean monthly rainfall follows the same broad pattern at each of the climate stations throughout the study area: that of summer and late spring predominance (Figure 2). Mean annual precipitation ranges from 744 mm at Bingara to 579 mm at Moree (Table 2).

Temperatures are hot during summer and cold during winter (Table 2). Moree and Narrabri have the highest mean monthly temperatures of the hottest month (34.8°C and 35.3°C respectively), while those stations in the Nandewar Bioregion (Tamworth, Bingara and Barraba) have the lowest mean minimum temperatures of the coldest month (2.9°C, 2.2°C, 0.2°C respectively) (Table 2).

The geology of the study area is a complex mixture of volcanic, sedimentary and metamorphic rocks. In the northern parts of the study area the geology is dominated by volcanic features, such as the Kaputar volcano (near Narrabri), the Inverell basalt flows east of Warialda, and the Quaternary alluvium derived from Tertiary basalts on the Liverpool Plains (between Quirindi and Narrabri) and the plains to the north and west of Warialda and north and north-east of Narrabri, and the sediments, shales and volcanics of the New England Fold Belt, which runs from

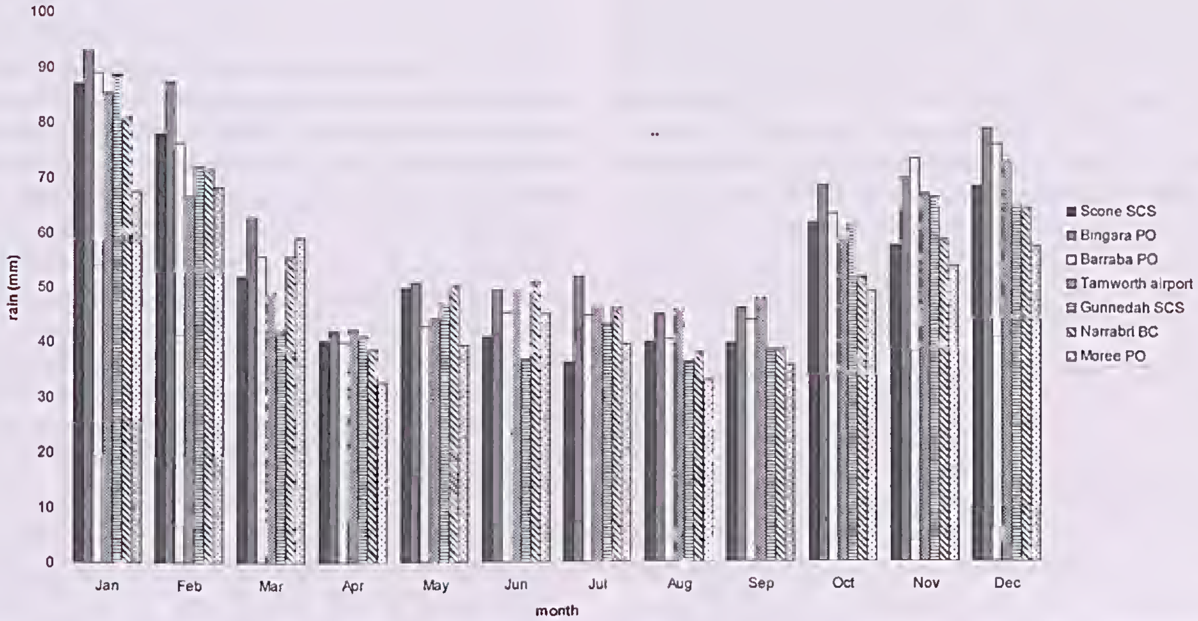


Fig. 2. Mean monthly rainfall at each of seven climate stations throughout the study area. SCS=Soil Conservation Station, PO=Post Office, BC=Bowling Club. Source: Bureau of Meteorology (2004).

the Hunter Valley to Warialda (NSW NPWS 2003). There is localised outcropping of Permian, Triassic and Jurassic sandstones among the basalts and Quaternary alluvium as well as scattered outcropping of serpentinite and limestone along the New England Fold Belt (NSW NPWS 2003). The upper Hunter Valley part of the study area largely comprises sedimentary rocks of Carboniferous or Permian age, with some volcanic intrusions (HCMT 2003).

The geomorphology of the study area includes alluvial plains (altitudes 200–300 m) along major river systems. These plains are often interspersed with low hills, while there are steep hills along the New England Fold Belt (some areas over 1000 m asl) and on the Kaputar volcano (areas over 1500 m asl).

Due to this diversity of geology and geomorphology, there is a wide range of soils in the study area (NSW NPWS 2003). Alluvial soils derived from basalt are usually deep, often heavy, black loams and clays of high fertility. The soils on basalt hills also are high nutrient clays and loams, usually red or brown in colour and stony or skeletal on the hill tops, increasing in depth further down slope. Sedimentary hills often have low nutrient, shallow soils on hill tops, grading to texture contrast soils further down slope. Dark, alkaline clays are usually formed from limestone.

The predominant vegetation of the study area is eucalypt woodland. In the BBS Bioregion, this mainly comprises grassy box woodland, dominated by *Eucalyptus albens*, *Eucalyptus populnea* or *Eucalyptus pilligaensis*, often with several species of ironbark eucalypts (Benson 1999). These equate to the Western Slopes Grassy Woodlands class of Keith (2004). Benson (1999) notes that there are also extensive stands of *Callitris glaucophylla* dominated woodland (Western Slopes Dry Sclerophyll Forests and Yetman Dry Sclerophyll Forests *sensu* Keith 2004), and more restricted patches of *Casuarina cristata* and *Acacia harpophylla* (Brigalow Clay Plain Woodlands *sensu* Keith 2004). The NAN Bioregion and hilly terrain of the BBS Bioregion are dominated by North-West Slopes Dry Sclerophyll Woodlands (Keith 2004). The woodlands of the upper Hunter are often dominated by *Eucalyptus moluccana*, *Eucalyptus albens* or *Eucalyptus crebra* (HCMT 2003) and comprise the Coastal Valley Grassy Woodlands, Hunter Macleay Dry Sclerophyll Forests and North-west Slopes Dry Sclerophyll Woodlands classes of Keith (2004).

Dry rainforest (in this sense encompassing both the Dry Rainforest and Western Vine Thickets classes of Keith 2004) occurs only patchily throughout the study area, and rarely occurs in large contiguous stands. However, in many situations dry rainforest (particularly SEVT) forms a transition with adjacent vegetation, particularly North-west Slopes Dry Sclerophyll Woodlands, and to a much lesser extent Brigalow Clay Plain Woodlands (Keith 2004). At a regional scale, it is not feasible to map the very small patches of dry rainforest within this larger transitional vegetation type. DLWC (2002) provided a suitable means of dealing with this circumstance by describing the vegetation community Dry Scrubs (Table 1).

Sampling design

The usual method of identifying sites for sampling for regional floristic surveys is via a stratification process which incorporates a range of environmental variables, such as parent material (geology), elevation (surrogate for climate and rainfall) and terrain (Keith and Bedward 1999; Benson and Ashby 2000). However, it is difficult to use such methods when undertaking targeted surveys of a particular vegetation community, especially when the distribution of that community is not completely known and it can be difficult to detect via aerial photography. Prober and Thiele (2004) encountered a similar problem when conducting their survey of grassy box woodlands. They sought sites with a predominately intact native understorey, which were very rare in their study area. Consequently, they conducted little *a priori* stratification (land use and overstorey composition only) and subjectively chose sites within land use classes as random sampling would have resulted in the survey of weedy, highly disturbed sites.

A similar approach was adopted for this survey of the dry rainforests of the western slopes of NSW, albeit without the additional caveat of not sampling highly weedy sites. Early trials at identifying dry rainforest from aerial photography showed that while this method was of considerable utility in reliably detecting certain types of dry rainforest (e.g. dry rainforest of gullies, gorges and scree slopes), it produced variable results for other types, particularly SEVT. In some instances known patches of SEVT were not discernible on aerial photographs, and sometimes patches of vegetation that showed promising structure, colour and texture on aerial photographs proved, upon field inspection, to be other types of vegetation (dense *Acacia* spp. thickets or dense shrub layers). Several government vegetation mapping programs were being undertaken during the course of this study, and it was not possible to borrow or view complete aerial photograph coverage for the study area. Hence, it was not possible to undertake *a priori* stratification of dry rainforest sites. Instead, dry rainforest sites were identified using the various means outlined below and subsequently sampled. Every effort was made to establish good coverage of the study area, similar to the aim of Prober and Thiele (2004), and to sample all of the geological and landscape systems that support dry rainforest. This concords with the goal of Russell-Smith (1991) who aimed to sample as many rainforest patches as possible in the Northern Territory over the full geographical and ecological extent of the vegetation type.

Potential dry rainforest survey sites were identified in a number of different ways. The primary means of site selection was interpretation of aerial photographs. This entailed viewing stereo pairs of the latest 1:25 000 scale colour photographs for parts of the study area where coverage was available. Potential sites were assigned a priority code on a three-point scale, based on the likelihood of the sites being dry rainforest. Due to incomplete coverage of the study area—many aerial photographs were not available because of other mapping programs—aerial photograph interpretation was undertaken only for the following 1:100 000 scale map sheets: Curlewis, Boggabri, Tamworth, Manilla, Horton, and Bingara.

Aerial photograph interpretation was then complemented via the means listed below. Firstly, a literature search (both published literature and unpublished species lists) was undertaken to identify potential sites. This included reports by Story (1963a), Turner (1976), Holmes (1979), Beadle (1981); Pulsford (1983), Williams (1983), Floyd (1990), Benson (1993), Benson et al. (1996), McDonald (1996) and Cooper & McAllen (1999). All documented occurrences of dry rainforest were identified as potential study sites. These were usually visited prior to survey to confirm the existence of dry rainforest. Secondly, advantage was taken of any opportunistic encounters with dry rainforest patches identified during vehicle and foot traverses across the study area. In some instances, potential sites identified by other means (e.g. aerial photograph interpretation) were cross-referenced with observations from these traverses to confirm their designation as potential study sites. Finally, where fine-scale vegetation mapping had been undertaken across the study area, this was used to further identify potential study sites. Two approaches were used: 1) in instances where large stands of dry rainforest were identified and mapped (e.g. Peasley and Walsh 2001; DLWC 2002), these were logged as survey sites and subsequently sampled; and 2) following liaison with botanists and cartographers involved with the production of these maps, other areas of potential dry rainforest (usually too small to be shown as polygons on the mapping) were identified for future survey.

Sampling methods

Vegetation was sampled in 0.04 ha quadrats, which is a standard size used by the National Herbarium of NSW, the NSW National Parks and Wildlife Service (now Department of Environment and Climate Change), State Forests of NSW and the Department of Infrastructure and Planning and Natural Resources (now Department of Natural Resources) for full floristic surveys in NSW (Keith and Bedward 1999; Benson and Ashby 2000; DLWC 2002). Quadrats were mostly square in alignment (20 x 20 m), except where the configuration of dry rainforest patches precluded this. In such instances the dimensions and alignment of the plot were adjusted to ensure that the area of the quadrat was located within dry rainforest vegetation and totalled 0.04 ha.

All vascular plant taxa evident in each quadrat at the time of sampling were recorded. During some survey periods, e.g. the drought of 2002, certain plant life forms (e.g. forbs and grasses) either lacked aboveground parts or could not be identified due to lack of reproductive organs. Voucher specimens were collected, generally at least one from each taxon, for deposition in the N.C.W. Beadle Herbarium (NE) and/or to confirm identity. The identity of specimens was checked against material contained in NE, usually in collaboration with relevant specialists from NE. Nomenclature in this study follows the Flora of NSW (Harden 1990–1993; 2002; Harden and Murray 2000) or more recent treatments of rainforest flora (Harden et al. 2006) or grasses (Wheeler et al. 2002) with some exceptions following recent literature in line with the curation of NE; families generally follow Stevens (2001 onwards).

Each taxon present was allocated a cover-abundance score based on a modified six-point Braun-Blanquet scale (Poore 1955). The categories used for this scale were slightly different to those used by Keith and Bedward (1999) and Benson and Ashby (2000), but were the same as those of Austin et al. (2000) and DEC (2004a); viz: 1=cover <5% site and uncommon; 2=cover <5% and common; 3=6–20%; 4=21–50%; 5=51–75%; 6=76–100%.

The structure of the vegetation at each site was described by estimating the height and percentage crown cover (Walker and Hopkins 1990) of each of up to four vegetation strata: emergent, tallest canopy stratum, mid-stratum, ground cover up to 1m height.

Table 3. Sources of floristic data used in analyses for this paper

Source	Description	Site labels
This paper	Dry rainforest of the North Western Slopes of NSW	TC003–134
Peake (2006) and Peake and Curran (unpub.)	Vegetation of the Central Hunter Valley: sites from dry rainforest	GNG56–58; RBR01; GRETA2; Q002, 012, 037–038, 037–038, 045, 053–54; WLA04–05; SCN19–24, 26–28, 31–35
DEC (2004a)	Vegetation of the Nandewar Bioregion: sites from dry rainforest	NBAFF0184, 0256, 0329, 0388–0389, 0402, 0436, 0444, 1336, 1346
Benson *et al.* (1996)	Semi-evergreen vine thicket vegetation at Derra Derra Ridge	MVT001–005, MVT007
Benson (1993)	*Cadellia pentastylis* vegetation in NSW	OOL01–32

Most sampling of quadrats was undertaken between June 2001 and September 2002, although one quadrat was sampled in each of March and April 2004.

Additional data and data compatibility

To complement the dry rainforest data collected for this study, data on dry rainforest vegetation for the study area were obtained from several other sources (Table 3). Firstly, dry rainforest data from the Hunter Valley from Peake (2006) were included. These data were from dry rainforest communities identified by Peake (2006) and from Peake and Curran (unpub.) from dry rainforest communities at Brushy Hill near Scone and Mt Dangar in Goulburn River National Park. Secondly, ten sites, sampled by several different operators for DEC (2004a) in the Nandewar Bioregion and assigned to dry rainforest communities were included. Thirdly, six of the seven sites sampled at Derra Derra Ridge near Bingara by Benson et al. (1996) were included. The site that was omitted was a *Triodia*–dominated hummock grassland. Finally, data collected by Benson (1993) from sites in *Cadellia pentastylis* dominated forest on the North Western Slopes of NSW, including one site from Ooline Gorge, Sundown National Park, Queensland were added.

The use of data from different sources meant that the combined data set had to be made compatible. All sources used a modified Braun–Blanquet scale to estimate the cover–abundance of taxa recorded in sites of 400 m^2 area. DEC (2004a) used the same cover–abundance scale as this study, so no adjustment was required. Benson et al. (1996) used a slightly different scale based on Benson (1994): a score of 3 on this scale represented cover from 5–25% and a score of 4 a cover of 26–50%. However, it was not possible to adjust data to the scale used in this study, so data from Benson et al. (1996) were used without change. Peake (2006) also used a slightly different scale, a score of 5 reflected cover of 50–70% and a score of 6 represented cover of 70–100%, which also was not adjusted. Benson (1993) used a seven-point scale, with plants with only one individual scored 1, and other categories similar to Benson (1994), so scores were amended by combining scores of 1 and 2 in Benson (1993) to a score of 1 for analysis. Benson (1993) also provided counts of individuals for all *Cadellia pentastylis* in all plots and for some other taxa in some plots in lieu of cover–abundance scores. These counts were converted to cover–abundance scores by the following scheme: 0–5 individuals=cover–abundance score 3; 6–15 individuals=score 4; 16–25 individuals=score 5; 25+ individuals=score 6.

All taxa that could not be identified to species level were removed from the data set. Any taxa that were identified to different levels of specificity, e.g. identified to species in one source and to subspecies level by another source, were reconciled. Where species level taxa could reliably be assigned to a subspecies or variety (e.g. only one subspecies is known from the study area or from the state) this was done, otherwise all entries were assigned to the species level. For instance, all specimens of *Elaeodendron australe* that were sampled on the North Western Slopes and North Western Plains were identified as *Elaeodendron australe* var. *integrifolium*. However, in the Upper Hunter Valley both *Elaeodendron australe* var. *integrifolium* and *Elaeodendron australe* var. *australe* occur and were sometimes both found in the same plot. Indeed, as Peake (2006) noted, some individuals had leaf morphology characteristics of both varieties. Consequently, all records of *Elaeodendron australe* were assigned to the species level for analysis. Specimens of three taxa comprised amalgamation of two species each; *Austrostipa ramosissima/A. verticillata*, which comprised two closely related species that can only be differentiated when in fruit, and *Pellaea falcata/P. nana* and *Adiantum aethiopicum/A. atroviride*, where specimens could not be consistently reconciled with current separate treatments of the respective species.

Two species recorded by Benson (1993) were amended according to the rules used by DEC (2004a): *Acalphya capillipes* was removed as a possible misidentification and *Croton insularis* was changed to *Croton phebalioides*, reflecting the more likely taxon on the North Western Slopes of NSW. Two additional changes were made: *Olearia viscosa* was included in *Olearia* sp. aff. *elliptica* and *Canthium oleifolium* was subsumed in *Canthium odoratum* (now *Psydrax odorata*).

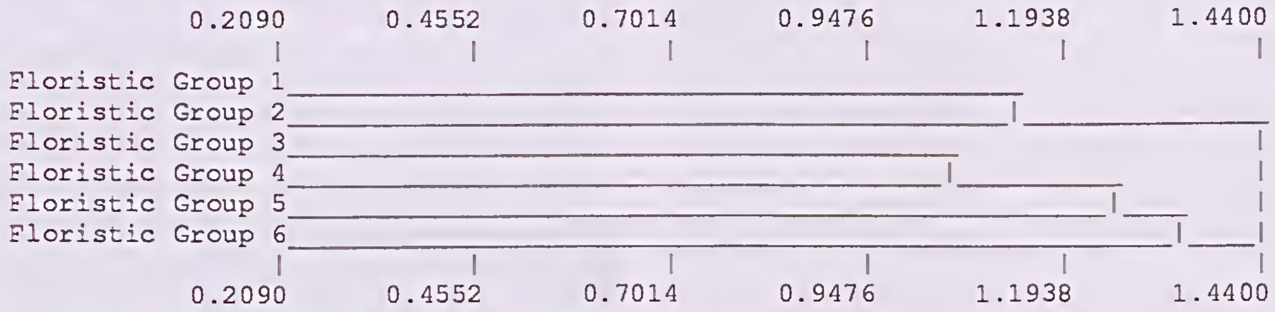
Statistical analyses

Data were explored using multivariate classification and ordination techniques. Classification was undertaken using the PATN computer program (Belbin 1993a). An unweighted pair-group arithmetic averaging (UPGMA) clustering strategy was applied to association matrices derived from the symmetric form of the Kulczynski similarity measure. This similarity measure is considered to be the most suitable with which to analyse ecological data (Belbin 1993b), because dissimilarity between sites is calculated on the basis of shared species, not species absences (Benson and Ashby 2000). Consequently this measure is more suitable in circumstances where species might be absent from sites for reasons (e.g. season of sampling) other than habitat preferences (Benson and Ashby 2000). Default options were used for the UPGMA: there was no adjacency constraint, no order of the output of the association matrix, and beta was set at -0.1. Ordination of the species and sites matrix, using Detrended Correspondence Analysis (DCA) in the package CANOCO (ter Braak and Šmilauer 1998), was undertaken to complement and aid interpretation of the cluster analysis.

Description of floristic groups

Floristic groups were described from summaries of floristic data, and by using the diagnostic species approach modified from Keith and Bedward (1999). This approach identifies species which delineate the target assemblage from the residual vegetation (all remaining sites) in the study area

Fig. 3. Summary dendrogram of cluster analysis on cover-abundance scores for all native species using the Kulczynski similarity coefficient. Scores above and below the dendrogram are the dissimilarity levels.



(Table 4). Four categories of species are identified (Table 4): 1) positive diagnostic species, which are more likely to be found in the target assemblage than in other assemblages; 2) negative diagnostic species, which are common in residual vegetation but rare in the target assemblage; 3) frequent species, which are common in all assemblages; and 4) uninformative species, which do not show clear distributional patterns in either target or residual assemblages (Keith and Bedward 1999). The thresholds used to distinguish types of diagnostic species in this project differ from those of Keith and Bedward (1999): a frequency of 0.35 is used instead of 0.5 as the upper threshold for the target assemblage and a frequency of 0.05 is used instead of 0 for the lower frequency threshold.

Plant attribute categorisation

Each taxon was assigned to a growth form group (trees, shrubs, vines, herbs, parasites, cycads or ferns) based on the Flora of NSW (Harden 1990–93). All trees, except exotic species, were further categorized as non-rainforest (all members of the genera *Acacia*, *Angophora*, *Callitris*, *Casuarina*, *Corymbia*, and *Eucalyptus*) or rainforest. All rainforest trees were then assigned to a leaf size class based on Webb (1959; 1968) using data from the Flora of NSW (Harden 1990–1993) or collected by Curran (2006). For trees with compound leaves, leaflet size was used to assign size classes. For each group the proportion of tree species in a given leaf size or leaf retention category was calculated based on either total rainforest tree species richness or proportion of importance index for that floristic group. The importance index gave a measure of species abundance and was derived as the product of median cover-abundance score and target frequency.

The height of the rainforest canopy for each site was derived from the midpoint of the estimated upper and lower height ranges of the canopy. No data were available for the sites from Benson et al. (1996), for the sites from DEC (2004a) or for sites RBR01, SCN31–35. Data from these sites were not used in the calculations of mean canopy height.

Results

Floristic composition

The final data set comprised 498 taxa from 208 sites. Of these, 73 taxa (14.7%) were naturalised exotics, not native to the study area, and were excluded from analyses. Of the remaining 425 taxa, 90 (21.2%) are singletons, taxa that occur in only one site. Analyses were conducted both with singletons retained and removed to test the robustness of the results of the cluster analysis. This had little effect on results; those presented here are with singletons retained.

These 498 taxa are from 99 families, including five families of pteridophytes, two families of gymnosperms and 92 families of angiosperms. The families with the highest number of taxa are: Poaceae (74 taxa), Asteraceae (44), Fabaceae (40), Myrtaceae (17), Solanaceae (16), Chenopodiaceae (14), Cyperaceae (13), Malvaceae (13), Eupomatiaceae (12), Asclepiadaceae (11), and Sapindaceae (9).

The most common taxon was *Notelaea microcarpa* var. *microcarpa*, which occurred in 195 (94%) of the 208 sites.

Table 4. Explanation of diagnostic species (modified from Keith and Bedward 1999). C/A=cover–abundance, Freq=frequency.

		Residual assemblages		
		Freq≥0.5 & C/A≥2	**Freq<0.5 or C/A<2**	**Freq≤0.05**
Target assemblages	**Freq≥0.35 & C/A≥2**	Frequent	Positive diagnostic	Positive diagnostic
	Freq<0.35 or C/A<2	Uninformative	Uninformative	Positive diagnostic
	Freq≤0.05	Negative diagnostic	Uninformative	-

Table 5. Leaf size classes and leaf phenology of the rainforest trees sampled in the study area. Leaf size classes follow Webb (1959; 1968).

Taxon	Leaf size class	Deciduous?
Alectryon forsythii	Microphyll	No
Alectryon oleifolius subsp. *elongatus*	Notophyll	No
Alectryon subcinereus	Notophyll	No
Alectryon subdentatus f. *subdentatus*	Microphyll	No
Alphitonia excelsa	Microphyll	No
Alstonia constricta	Notophyll	No
Atalaya hemiglauca	Notophyll	No
Backhousia myrtifolia	Microphyll	No
Brachychiton populneus subsp. *populneus*	Microphyll	No
Cadellia pentastylis	Microphyll	No
Capparis mitchellii	Microphyll	No
Claoxylon australe	Notophyll	No
Clerodendrum tomentosum	Notophyll	No
Codonocarpus attenuatus	Notophyll	No
Daphnandra apatela	Notophyll	No
Dysoxylum fraserianum	Notophyll	No
Ehretia acuminata var. *acuminata*	Notophyll	Yes
Ehretia membranifolia	Microphyll	Yes
Elaeocarpus obovatus	Notophyll	No
Elaeodendron australe	Microphyll	No
Eremophila mitchellii	Microphyll	No
Eupomatia laurina	Notophyll	No
Exocarpos cupressiformis	Nanophyll	No
Ficus coronata	Notophyll	No
Ficus rubiginosa	Notophyll	No
Geijera parviflora	Notophyll	No
Geijera salicifolia var. *salicifolia*	Notophyll	No
Hymenosporum flavum	Notophyll	No
Maytenus bilocularis	Microphyll	No
Melia azedarach	Microphyll	Yes
Melicope micrococca	Notophyll	No
Myrsine howittiana	Notophyll	No
Myrsine variabilis	Microphyll	No
Notelaea microcarpa var. *microcarpa*	Microphyll	No
Notelaea microcarpa var. *velutina*	Microphyll	No
Notelaea venosa	Notophyll	No
Owenia acidula	Microphyll	No
Owenia X reliqua	Microphyll	No
Pararchidendron pruinosum var. *pruinosum*	Microphyll	No
Pittosporum angustifolium	Notophyll	No
Pittosporum spinescens	Nanophyll	No
Pittosporum undulatum	Notophyll	No
Pouteria cotinifolia var. *pubescens*	Microphyll	No
Santalum lanceolatum	Microphyll	No
Streblus brunonianus	Microphyll	No
Trema tomentosa var. *viridis*	Microphyll	No
Ventilago viminalis	Notophyll	No

Other common taxa were: *Pandorea pandorana* (152 sites 73%), *Spartothamnella juncea* (143 sites, 69%), *Austrostipa* spp. (*A. verticillata*/*A. ramosissima*) (133 sites, 63.9%) and *Geijera parviflora* (129 sites, 62.0%). *Opuntia stricta* var. *stricta* was the most commonly recorded exotic taxon (102 sites, 49%), while other common exotic taxa included: *Malvastrum americanum* (46 sites, 22%), *Bidens pilosa* (37 sites, 18%), *Sonchus oleraceus* (20 sites, 10%) and *Bidens subalternans* and *Opuntia aurantiaca* (each 18 sites, 9%).

The mean richness of the 208 sites was 31.6, while the median richness was 31. The lowest richness was 11 taxa at OOL31 and TC081, while the highest was 69 taxa at TC047.

Three of the 47 rainforest tree species are deciduous, the remainder being evergreen (Table 5). Twenty two of these tree species have microphyll leaf size, 23 are notophyll and two are nanophyll leaf size.

Floristic classification

The results of the cluster analysis are summarized in Figure 3. Removal or inclusion of singletons had no effect on the outcome of analyses, so results here represent analyses on all native species. Six floristic groups were delineated, all at a high level of dissimilarity (>1.0). The first split in the dendrogram (at a dissimilarity level of 1.44) separated Floristic Groups 1 and 2 from Floristic Groups 3, 4, 5 and 6. In this latter cluster, Floristic Group 6 separated from the remaining groups at a dissimilarity level >1.3. Floristic Group 5 separated at a dissimilarity level >1.2, leaving groups 3 and 4 as the most similar of all groups delineated in this study.

The results of the ordination using DCA largely support the categorization of sites using cluster analysis (Figure 4). Several groups delineated in the cluster analysis, particularly Groups 2, 5 and 6, are clearly separate in ordination space.

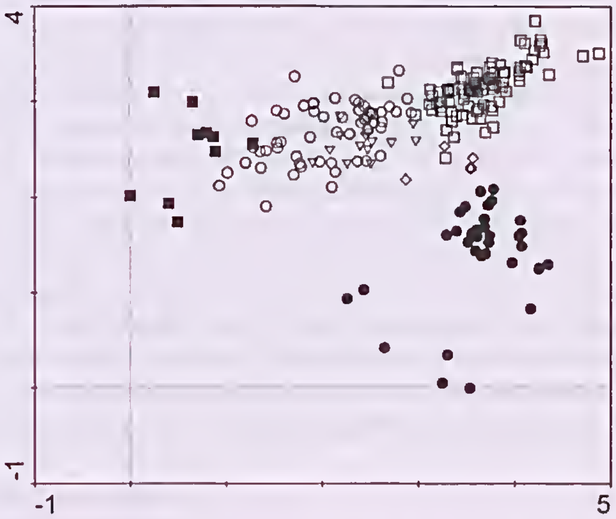


Fig. 4. Biplot showing the relationship of the sites to each other on the first two axes of the DCA ordination. Sites are denoted by symbols reflecting their grouping in the cluster analysis: ○=Group 1; ■=Group 2; ◇=Group 3; ▽=Group 4; □=Group 5; ●=Group 6.

Group 3, with only six sites, is also generally separate from other groups. However, there is substantial overlap between sites from Groups 1 and 4 (Figure 4)

Each floristic group is described below.

Floristic Group 1

This floristic group (Figures 5–8) is dominated by *Notelaea microcarpa* var. *microcarpa* and *Ficus rubiginosa* (Table 6), with occasional *Eucalyptus albens* or *Angophora floribunda* as emergents. Other rainforest canopy species include *Brachychiton populneus* subsp. *populneus*, *Alectryon subdentatus* f. *subdentatus*, *Alphitonia excelsa*, and *Alectryon forsythii*. The shrub layer is dominated by *Pimelea neo-anglica*, *Abutilon oxycarpum*, *Olearia* sp. aff. *elliptica*, and *Spartothamnella juncea*, while *Melicytus dentatus* is found in this floristic group much more frequently than in other floristic groups. *Pandorea pandorana*, *Eustrephus latifolius*, *Glycine tabacina* and *Clematis glycinoides* var. *glycinoides* are the dominant vines, while *Cayratia clematidea* and *Celastrus australis* are characteristic vines of this group. The ground layer is dominated by herbs such as *Microlaena stipoides* var. *stipoides*, *Urtica incisa*, *Austrostipa verticillata/A. ramosissima*, *Dichondra* species A, *Oplismenus aemulus* and *Rumex brownii* and ferns such as *Adiantum aethiopicum/A. atroviride* and *Pellaea calidirupium*.

There were 56 plots in Floristic Group 1. The mean species richness for a 0.04 ha plot in this group was 32 ± 1. The lowest richness was 11 taxa in plot TC081 and the highest 59 taxa in plot NBAFF0436.

Table 6. Diagnostic species of Floristic Group 1. CA=cover-abundance.

Species	Growth form	Target frequency	Target CA	Residual frequency	Residual CA	Fidelity class
Notelaea microcarpa var. *microcarpa*	tree	0.98	3	0.93	3	frequent
Ficus rubiginosa	tree	0.82	3.5	0.07	3	positive diagnostic
Brachychiton populneus subsp. *populneus*	tree	0.41	1	0.18	1	positive diagnostic
Alectryon subdentatus f. *subdentatus*	tree	0.36	3	0.11	2.5	positive diagnostic
Alphitonia excelsa	tree	0.36	1	0.20	1.5	positive diagnostic
Alectryon forsythii	tree	0.29	3	0.00	0	positive diagnostic
Pimelea neo-anglica	shrub	0.55	1	0.39	1	uninformative
Abutilon oxycarpum	shrub	0.48	1	0.48	1	uninformative
Olearia sp. aff. *elliptica*	shrub	0.45	1	0.37	2	uninformative
Spartothamnella juncea	shrub	0.43	1	0.79	2	uninformative
Solanum parvifolium	shrub	0.39	2	0.56	1	positive diagnostic
Melicytus dentatus	shrub	0.27	1	0.05	2	positive diagnostic
Pandorea pandorana	vine	0.86	2	0.69	2	frequent
Eustrephus latifolius	vine	0.52	1	0.13	1.5	uninformative
Glycine tabacina	vine	0.48	1	0.42	1	uninformative
Clematis glycinoides var. *glycinoides*	vine	0.43	1	0.11	1	uninformative
Cayratia clematidea	vine	0.39	2	0.15	2	positive diagnostic
Celastrus australis	vine	0.27	2	0.03	2	positive diagnostic
Microlaena stipoides var. *stipoides*	herb	0.77	2	0.07	1	positive diagnostic
Urtica incisa	herb	0.70	1	0.23	1	uninformative
Austrostipa verticillata/A. ramosissima	herb	0.55	1	0.68	2	uninformative
Dichondra species A	herb	0.54	1	0.31	1	uninformative
Oplismenus aemulus	herb	0.46	2	0.04	1	positive diagnostic
Rumex brownii	herb	0.45	1	0.04	1.5	positive diagnostic
Scleria mackaviensis	herb	0.43	1	0.21	1	uninformative
Arthropodium species B	herb	0.39	1	0.03	1	positive diagnostic
Elymus scaber	herb	0.36	1	0.02	1	positive diagnostic
Geranium solanderi var. *solanderi*	herb	0.27	1	0.04	2	positive diagnostic
Adiantum aethiopicum/A. atroviride	fern	0.48	2	0.04	2.5	positive diagnostic
Pellaea calidirupium	fern	0.45	2	0.02	1	positive diagnostic
Asplenium flabellifolium	fern	0.23	1	0.04	1	positive diagnostic

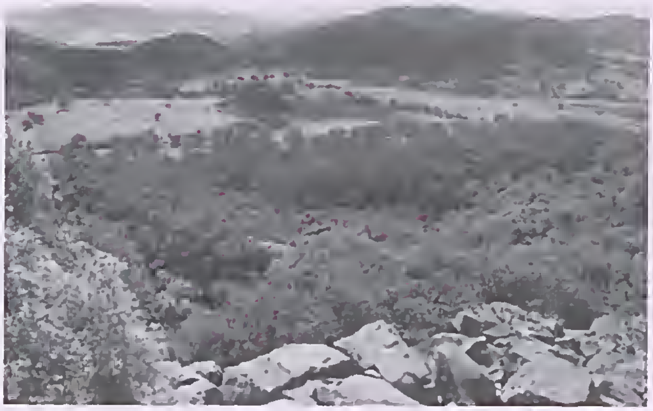


Fig. 5. *Ficus rubiginosa–Notelaea microcarpa* notophyll vine thicket (Floristic Group 1) on an andesite scree slope, Duri Mountain, near Currabubula, south of Tamworth. The low height of the vine thicket can be seen in comparison to the adjacent eucalypt woodland in the middle ground. The scree slope demarcates these two communities.

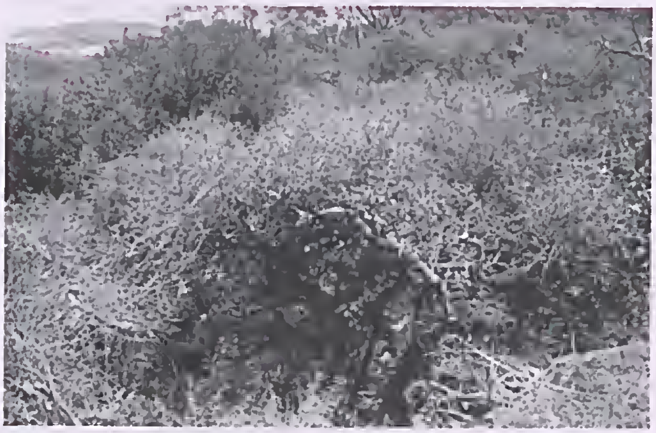


Fig. 6. Interior of *Ficus rubiginosa–Notelaea microcarpa* notophyll vine thicket (Floristic Group 1) stand, Duri Mountain. *Alectryon forsythii* and *Ficus rubiginosa* dominate the canopy and there is a dense layer of moss on the scree boulders.

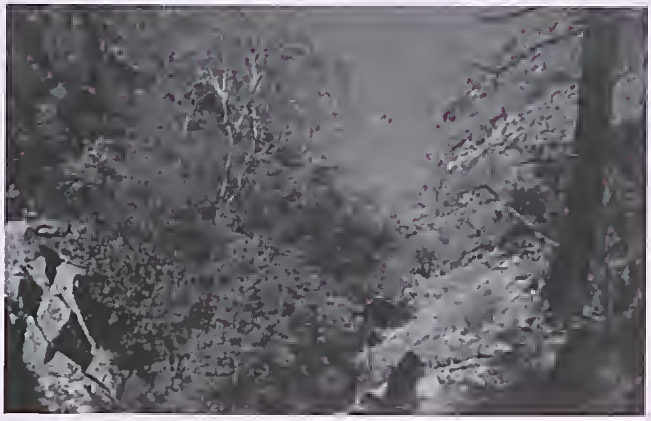


Fig. 7. *Ficus rubiginosa–Notelaea microcarpa* notophyll vine thicket (Floristic Group 1) in a gully on a trachyte outcrop, Yulludunida Crater, Mt Kaputar National Park, near Narrabri.

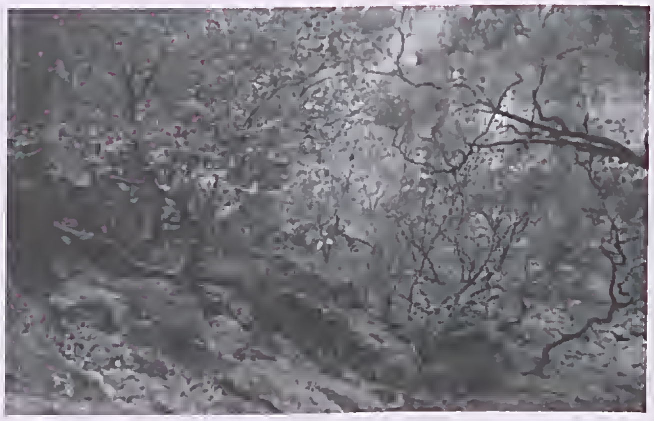


Fig. 8. Interior of *Ficus rubiginosa–Notelaea microcarpa* notophyll vine thicket (Floristic Group 1) in a trachyte gorge, Waa Gorge, Mount Kaputar National Park.

Floristic Group 2

Ficus rubiginosa, *Alectryon subcinerens*, *Notelaea microcarpa* var. *microcarpa* and *Clerodendrum tomentosum* dominate this community (Table 7; Figures 9 & 10), with *Casuarina cunninghamiana* subsp. *cunninghamiana* an occasional emergent in creekline stands. Other characteristic tree species are *Melia azedarach*, *Backhousia myrtifolia*, *Daphnandra apatela*, *Ficus coronata*, *Myrsine variabilis* and *Claoxylon australe*. The shrub layer is dominated by *Melicytus dentatus*, *Breynia oblongifolia* and *Spartothamnella juncea*. Common vines are *Eustrephus latifolius*, *Pandorea pandorana*, *Cissus antarctica*, *Cayratia clematidea* and *Clematis glycinoides* var. *glycinoides*, with *Aphanopetalum resinosum* among the characteristic vine species. The ground layer is dominated by herbs such as *Urtica incisa*, *Nyssanthes diffusa*, *Geranium solanderi* var. *solanderi*, *Galium aspera* and *Solenogyne bellioides* and ferns such as *Pellaea falcata*/*P. nana* and *Adiantum formosum*.

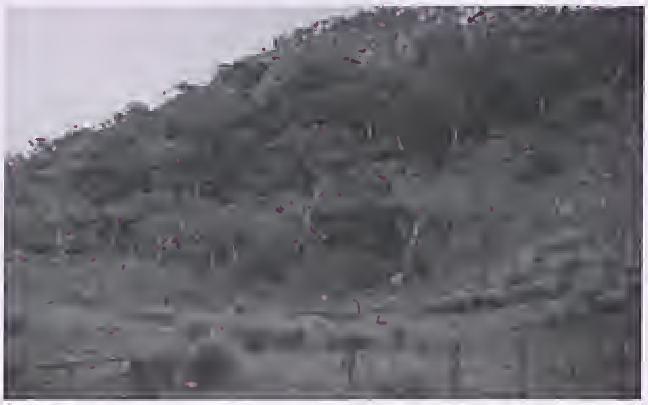


Fig. 9. *Ficus rubiginosa–Alectryon subcinerens–Notelaea microcarpa* notophyll vine forest (Floristic Group 2) on a scree slope of Carboniferous volcanics at Segenhoe Mountain, near Aberdeen, upper Hunter Valley. The deciduous tree is *Melia azedarach*.

Table 7. Diagnostic species of Floristic Group 2.

Species	Growth form	Target frequency	Target CA	Residual frequency	Residual CA	Fidelity class
Ficus rubiginosa	tree	0.8	3	0.247	4	positive diagnostic
Alectryon subcinereus	tree	0.8	3	0.010	1.5	positive diagnostic
Notelaea microcarpa var. *microcarpa*	tree	0.8	2	0.944	3	frequent
Clerodendrum tomentosum	tree	0.8	1	0.051	1.5	uninformative
Melia azedarach	tree	0.4	2	0.030	1	positive diagnostic
Backhousia myrtifolia	tree	0.3	3	0.000	0	positive diagnostic
Daphnandra apatela	tree	0.3	2	0.000	0	positive diagnostic
Ficus coronata	tree	0.3	3	0.005	3	positive diagnostic
Myrsine variabilis	tree	0.3	2	0.010	1.5	positive diagnostic
Claoxylon australe	tree	0.3	1	0.010	3	positive diagnostic
Casuarina cunninghamiana subsp. *cunninghamiana*	tree	0.2	3	0.000	0	positive diagnostic
Hymenosporum flavum	tree	0.2	2.5	0.000	0	positive diagnostic
Geijera salicifolia var. *salicifolia*	tree	0.2	1.5	0.015	1	positive diagnostic
Myrsine howittiana	tree	0.2	1.5	0.000	0	positive diagnostic
Melicytus dentatus	shrub	0.8	2	0.076	1	positive diagnostic
Breynia oblongifolia	shrub	0.4	2.5	0.333	1	uninformative
Spartothamnella juncea	shrub	0.4	1	0.702	2	uninformative
Eustrephus latifolius	vine	0.9	2	0.202	1	positive diagnostic
Pandorea pandorana	vine	0.8	2	0.727	2	frequent
Cissus antarctica	vine	0.7	3	0.005	2	positive diagnostic
Cayratia clematidea	vine	0.6	2	0.197	2	positive diagnostic
Clematis glycinoides var. *glycinoides*	vine	0.6	2	0.172	1	positive diagnostic
Aphanopetalum resinosum	vine	0.4	2	0.005	3	positive diagnostic
Legnephora moorei	vine	0.2	2	0.000	0	positive diagnostic
Clematis aristata	vine	0.2	1.5	0.000	0	positive diagnostic
Urtica incisa	herb	0.8	2	0.328	1	positive diagnostic
Nyssanthes diffusa	herb	0.7	2	0.096	2	positive diagnostic
Geranium solanderi var. *solanderi*	herb	0.4	2	0.086	1	positive diagnostic
Gahnia aspera	herb	0.4	2	0.040	1	positive diagnostic
Solenogyne bellioides	herb	0.4	2	0.005	1	positive diagnostic
Cotula australis	herb	0.2	2	0.000	0	positive diagnostic
Lomandra longifolia	herb	0.2	2	0.040	1.5	positive diagnostic
Pratia purpurascens	herb	0.2	2	0.015	2	positive diagnostic
Dichondra species A	herb	0.2	2	0.379	1	uninformative
Ripogonum album	herb	0.2	2	0.000	0	positive diagnostic
Arctotheca calendula	herb	0.2	1.5	0.000	0	positive diagnostic
Echinopogon ovatus	herb	0.2	1.5	0.000	0	positive diagnostic
Pellaea falcata/P. nana	fern	0.7	2	0.101	2	positive diagnostic
Adiantum formosum	fern	0.5	2	0.000	0	positive diagnostic
Pyrrosia rupestris	fern	0.3	2	0.000	0	positive diagnostic

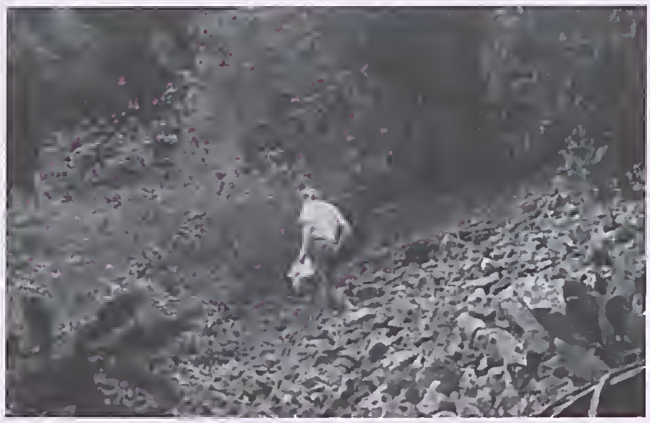


Fig. 10. Interior of *Ficus rubiginosa–Alectryon subcinereus–Notelaea microcarpa* notophyll vine forest (Floristic Group 2) on basalt scree at Lake Glenbawn, upper Hunter Valley. This community supports many vines, such as *Cissus antarctica* (to the left of Travis Peake).

There were 10 plots in Floristic Group 2. The mean species richness for a 0.04 ha plot in this group was 34 ± 3. The lowest richness was 16 taxa in plot GRETA2 and the highest 53 taxa in plot Q038.

Floristic Group 3

Floristic Group 3 is dominated by *Elaeodendron australe*, *Geijera parviflora* and *Notelaea microcarpa* var. *microcarpa*, with emergent species such as *Acacia salicina*, *Acacia cheelii*, *Callitris glaucophylla* and *Eucalyptus melanophloia* (Table 8). *Carissa ovata* and *Pimelea neo-anglica* are the most common shrubs along with *Beyeria viscosa*, *Correa glabra*, *Cryptandra longistaminea*, *Indigofera brevidens*, *Phyllanthus subcrenulatus* and *Spartothamnella juncea*. *Parsonsia eucalyptophylla* and *Pandorea pandorana* are the dominant vines. The ground layer is dominated by the herbs *Aristida ramosa*, *Dichondra repens* and *Thellungia advena* and the fern *Cheilanthes sieberi* subsp. *sieberi*.

Table 8. Diagnostic species of Floristic Group 3.

Species	Growth form	Target frequency	Target CA	Residual frequency	Residual CA	Fidelity class
Elaeodendron australe	tree	1.00	2.5	0.40	3	positive diagnostic
Geijera parviflora	tree	0.83	2	0.61	3	frequent
Notelaea microcarpa var. *microcarpa*	tree	0.83	2	0.94	3	frequent
Acacia salicina	tree	0.67	1	0.02	2	uninformative
Acacia cheelii	tree	0.50	1	0.01	1	uninformative
Callitris glaucophylla	tree	0.50	2	0.14	1	positive diagnostic
Eucalyptus melanophloia	tree	0.50	2	0.05	3	positive diagnostic
Carissa ovata	shrub	1.00	3	0.30	3	positive diagnostic
Pimelea neo-anglica	shrub	1.00	1	0.42	1	uninformative
Beyeria viscosa	shrub	0.67	1.5	0.41	2	uninformative
Correa glabra	shrub	0.50	2	0.00	0	positive diagnostic
Cryptandra longistaminea	shrub	0.50	2	0.00	0	positive diagnostic
Indigofera brevidens	shrub	0.50	1	0.08	1	uninformative
Phyllanthus subcrenulatus	shrub	0.50	1	0.20	1	uninformative
Spartothamnella juncea	shrub	0.50	1	0.69	2	uninformative
Parsonsia eucalyptophylla	vine	0.83	1	0.30	1	uninformative
Pandorea pandorana	vine	0.67	1	0.73	2	uninformative
Aristida ramosa	herb	1.00	2.5	0.14	1	positive diagnostic
Dichondra repens	herb	0.83	1	0.14	2	uninformative
Thellungia advena	herb	0.67	2	0.00	0	positive diagnostic
Boerhavia dominii	herb	0.50	1	0.04	1	positive diagnostic
Gahnia aspera	herb	0.50	1	0.04	1	positive diagnostic
Poa sieberiana var. *sieberiana*	herb	0.50	3	0.01	2.5	positive diagnostic
Carex breviculmis	herb	0.33	1	0.00	2	positive diagnostic
Chloris truncata	herb	0.33	1	0.03	1	positive diagnostic
Dianella revoluta	herb	0.33	1.5	0.03	1	positive diagnostic
Lomandra multiflora	herb	0.33	1	0.00	1	positive diagnostic
Cheilanthes sieberi subsp. *sieberi*	fern	0.67	1	0.37	1	uninformative

There were 6 plots in Floristic Group 3. The mean species richness for a 0.04 ha plot in this group was 28 ± 3. The lowest richness was 15 taxa in plot MVT007 and the highest 40 taxa in plot MVT003.

Floristic Group 4

This floristic group is dominated by *Elaeodendron australe*, *Geijera parviflora* and *Notelaea microcarpa* var. *microcarpa*, with *Alectryon oleifolius* subsp. *elongatus*, *Clerodendrum tomentosum* and, to a lesser extent *Melia azedarach*, the other important tree species (Table 9; Figures 11 & 12). *Eucalyptus albens* is commonly an emergent above this vine thicket canopy. The shrub layer is dominated by *Olearia* sp. aff. *elliptica*, *Rhagodia parabolica* and *Spartothamnella juncea*, with *Solanum brownii* and *Beyeria viscosa* also common. Vines are commonly encountered, particularly *Clematicissus opaca*, *Marsdenia flavescens*, *Parsonsia eucalyptophylla*, *Pandorea pandorana*, *Clematis glycinoides* var. *glycinoides*, *Parsonsia lanceolata* and *Tylophora grandiflora*. The

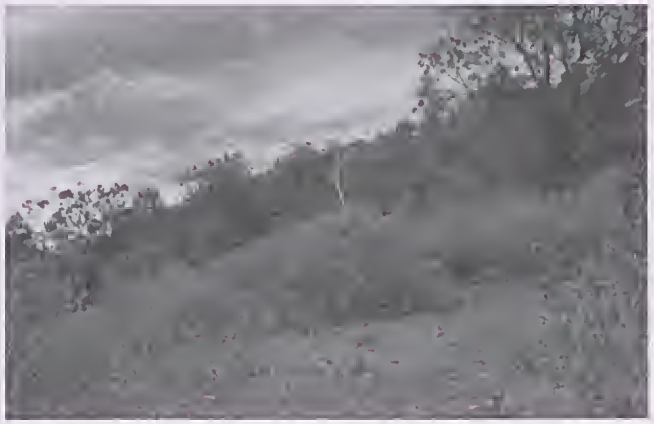


Fig. 11. *Elaeodendron australe–Notelaea microcarpa–Geijera parviflora* notophyll vine thicket (Floristic Group 4 middle ground on the photo) on the slopes of Brushy Hill, Lake Glenbawn, upper Hunter Valley. The shrub layer at the front is dominated by *Rhagodia parabolica*, a very common shrub in this community.

Table 9. Diagnostic species of Floristic Group 4.

Species	Growth form	Target frequency	Target CA	Residual frequency	Residual CA	Fidelity class
Elaeodendron australe	tree	1.00	3	0.37	3	positive diagnostic
Geijera parviflora	tree	0.93	3	0.60	3	frequent
Notelaea microcarpa var. *microcarpa*	tree	0.86	2	0.94	3	frequent
Alectryon oleifolius subsp. *elongatus*	tree	0.71	3	0.23	1	positive diagnostic
Clerodendrum tomentosum	tree	0.71	1.5	0.04	1	positive diagnostic
Eucalyptus albens	tree	0.71	3	0.14	3	positive diagnostic
Melia azedarach	tree	0.36	1	0.03	3	positive diagnostic
Olearia sp. aff. *elliptica*	shrub	1.00	3.5	0.35	1	positive diagnostic
Rhagodia parabolica	shrub	1.00	2.5	0.22	1	positive diagnostic
Spartothamnella juncea	shrub	1.00	2	0.66	1	positive diagnostic
Solanum brownii	shrub	0.71	2	0.03	2	positive diagnostic
Beyeria viscosa	shrub	0.57	2	0.40	2	positive diagnostic
Breynia oblongifolia	shrub	0.36	1	0.34	1	uninformative
Pysdrax odorata forma *buxifolia*	shrub	0.21	1	0.01	1	positive diagnostic
Clematicissus opaca	vine	0.93	2	0.12	2	positive diagnostic
Marsdenia flavescens	vine	0.93	3	0.00	0	positive diagnostic
Parsonsia eucalyptophylla	vine	0.79	1	0.28	1	uninformative
Pandorea pandorana	vine	0.71	2	0.73	2	frequent
Clematis glycinoides var. *glycinoides*	vine	0.64	1	0.16	1	uninformative
Parsonsia lanceolata	vine	0.57	1	0.28	1	uninformative
Tylophora grandiflora	vine	0.57	1	0.00	0	uninformative
Urtica incisa	herb	0.79	1	0.32	1	uninformative
Austrostipa verticillata/A. ramosissima	herb	0.64	2	0.64	1	positive diagnostic
Austrodanthonia fulva	herb	0.43	2	0.01	1	positive diagnostic
Stellaria flaccida	herb	0.29	1.5	0.00	0	positive diagnostic
Oxalis exilis	herb	0.21	1	0.02	1	positive diagnostic
Vittadinia sulcata	herb	0.21	1	0.02	1	positive diagnostic
Macrozamia concinna	cycad	0.43	1	0.00	0	positive diagnostic

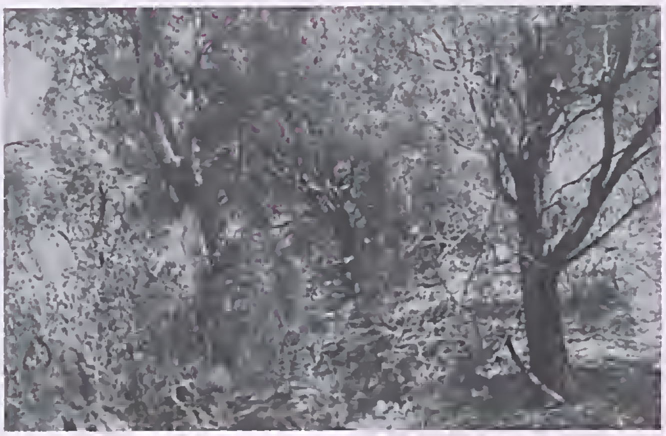


Fig. 12. Interior of *Elaeodendron australe–Notelaea microcarpa–Geijera parviflora* notophyll vine thicket (Floristic Group 4) on the slopes of Brushy Hill, Lake Glenbawn (see left background), upper Hunter Valley. *Notelaea microcarpa* and *Geijera parviflora* dominate the canopy here, while the main shrub is *Olearia* sp. aff. *elliptica*, a characteristic component of this community.

dominant herbs are *Urtica incisa*, *Austrostipa verticillata/A. ramosissima* and *Austrodanthonia fulva*. The cycad *Macrozamia concinna* is also occasionally encountered.

There were 14 plots in Floristic Group 4. The mean species richness for a 0.04 ha plot in this group was 34 ± 2. The lowest richness was 27 taxa in plot SCN020 and the highest 48 taxa in plot Q012.

Floristic Group 5

This group is consistently dominated by *Notelaea microcarpa* var. *microcarpa*, *Geijera parviflora* and *Ehretia membranifolia* (Table 10; Figures 13–15). *Elaeodendron australe* var. *integrifolia* and *Ventilago viminalis* become important components of the canopy north from Narrabri, and north from Yallaroi *Pouteria cotinifolia* var. *pubescens* and *Pittosporum spinescens* are co-dominants (Figure 14). The common shrubs are *Spartothamnella juncea*, *Solanum parvifolium*, *Abutilon oxycarpum*, *Beyeria viscosa*, *Rhagodia parabolica* and, north from Narrabri, *Carissa ovata*. Other characteristic shrubs include *Solanum mitchellianum* and *Enchylaena tomentosa*. The most common vines are *Clematis microphylla* var. *microphylla*, *Pandorea pandorana*, *Glycine tabacina*, *Jasminum lineare*, *Desmodium brachypodum*, *Parsonsia eucalyptophylla*, and *Parsonsia lanceolata*, while *Marsdenia viridiflora*, *Capparis lasiantha* and *Marsdenia pleiadenia* are particularly characteristic of this community. Herbs such *Austrostipa verticillata/A. ramosissima*, *Paspalidium gracile*, *Austrostipa scabra* subsp. *scabra*, *Leptochloa ciliolata*, and *Dichondra* species A, and the fern *Cheilanthes sieberi* subsp. *sieberi* dominate the ground layer, while herbs such as *Panicum queenslandicum* var. *queenslandicum*, *Chloris ventricosa*, *Austrodanthonia bipartita* and *Cymbopogon refractus* are characteristic of this floristic group.

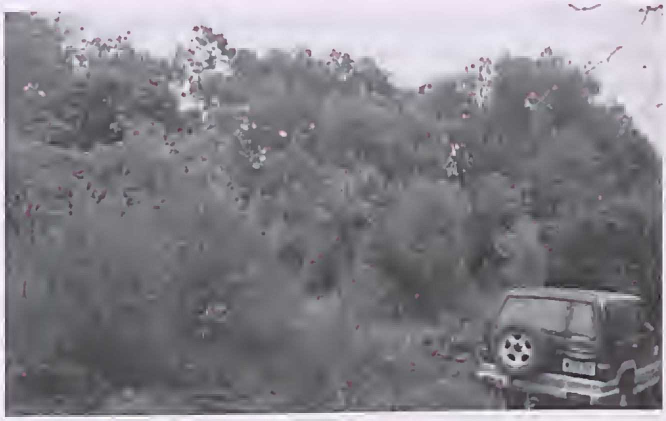


Fig. 13. *Notelaea microcarpa–Geijera parviflora–Ehretia membranifolia* semi evergreen vine thicket (Floristic Group 5) on a basalt hill, Derra Derra Ridge, near Bingara.

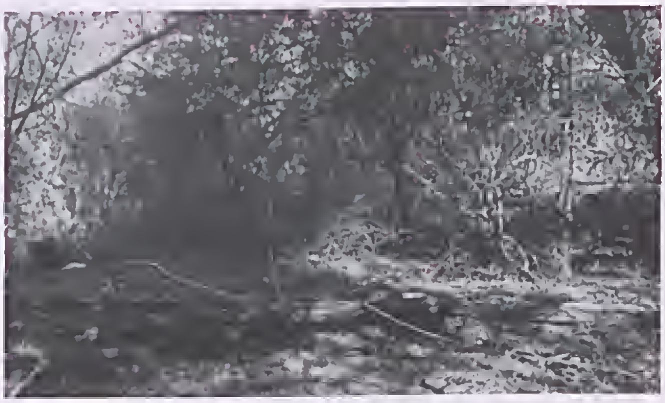


Fig. 14. Interior of *Notelaea microcarpa–Geijera parviflora–Ehretia membranifolia* semi-evergreen vine thicket (Floristic Group 5) on a basalt hill, near North Star, north-west of Warialda. Northern stands, such as this one are more complex in floristic composition, with *Pouteria cotinifolia* var. *pubescens* and *Pittosporum spinescens* co-dominants. *Carissa ovata* is a common shrub (middle background).

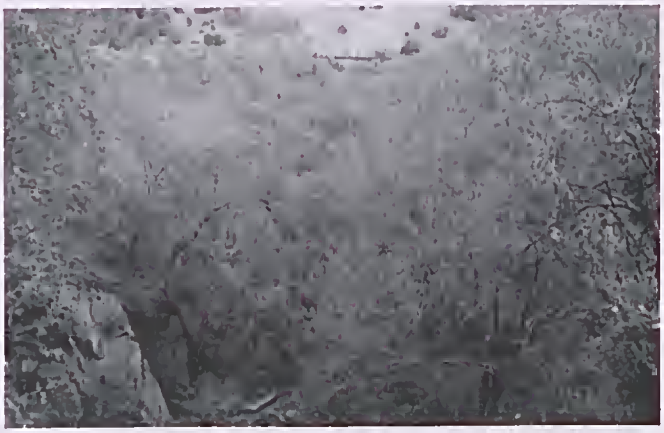


Fig. 15. Canopy of *Notelaea microcarpa–Geijera parviflora–Ehretia membranifolia* semi-evergreen vine thicket (Floristic Group 5) on Porcupine Hill, near Gunnedah. The deciduous tree in the canopy is *E. membranifolia*.

Table 10. Diagnostic species of Floristic Group 5.

Species	Growth form	Target frequency	Target CA	Residual frequency	Residual CA	Fidelity class
Notelaea microcarpa var. *microcarpa*	tree	0.97	3	0.92	3	frequent
Geijera parviflora	tree	0.92	3	0.39	1	positive diagnostic
Ehretia membranifolia	tree	0.79	3	0.09	1	positive diagnostic
Capparis mitchellii	tree	0.61	1	0.18	1	uninformative
Elaeodendron australe	tree	0.52	3	0.34	2	positive diagnostic
Alectryon oleifolius subsp. *elongatus*	tree	0.43	1	0.13	2	uninformative
Alstonia constricta	tree	0.34	2	0.24	1	uninformative
Ventilago viminalis	tree	0.33	2	0.01	1	positive diagnostic
Pittosporum spinescens	tree	0.15	2	0.00	0	positive diagnostic
Pouteria cotinifolia var. *pubescens*	tree	0.12	3	0.00	0	positive diagnostic
Spartothamnella juncea	shrub	0.87	1	0.55	1.5	uninformative
Solanum parvifolium	shrub	0.70	1	0.38	2	uninformative
Abutilon oxycarpum	shrub	0.60	1	0.39	2	uninformative
Beyeria viscosa	shrub	0.56	1	0.30	3	uninformative
Carissa ovata	shrub	0.52	3	0.17	3	positive diagnostic
Rhagodia parabolica	shrub	0.47	1	0.12	2.5	uninformative
Breynia oblongifolia	shrub	0.44	1	0.26	1	uninformative
Olearia sp. aff. *elliptica*	shrub	0.43	1	0.36	1	uninformative
Dodonaea viscosa	shrub	0.36	1	0.15	1	uninformative
Solanum mitchellianum	shrub	0.36	1	0.01	1	positive diagnostic
Enchylaena tomentosa	shrub	0.22	1	0.00	0	positive diagnostic
Clematis microphylla var. *microphylla*	vine	0.79	1	0.16	1	uninformative
Pandorea pandorana	vine	0.74	2	0.72	2	frequent
Glycine tabacina	vine	0.67	1	0.26	1	uninformative
Jasminum lineare	vine	0.61	2	0.18	1	positive diagnostic
Desmodium brachypodum	vine	0.42	1	0.18	1	uninformative
Parsonsia eucalyptophylla	vine	0.42	1	0.24	1	uninformative
Parsonsia lanceolata	vine	0.40	1	0.22	1	uninformative
Marsdenia viridiflora	vine	0.34	1	0.03	1	positive diagnostic
Capparis lasiantha	vine	0.26	2	0.00	0	positive diagnostic
Marsdenia pleiadenia	vine	0.22	1	0.02	1.5	positive diagnostic
Austrostipa verticillata/A. ramosissima	herb	0.85	1	0.48	2	uninformative
Paspalidium gracile	herb	0.61	1	0.07	1	uninformative
Austrostipa scabra subsp. *scabra*	herb	0.60	1	0.13	1	uninformative
Leptochloa ciliolata	herb	0:58	1	0.09	1	uninformative
Dichondra species A	herb	0.46	1	0.30	1	uninformative
Panicum queenslandicum var. *queenslandicum*	herb	0.31	1	0.02	1	positive diagnostic
Chloris ventricosa	herb	0.28	1	0.04	1	positive diagnostic
Austrodanthonia bipartita	herb	0.22	1	0.03	3	positive diagnostic
Cymbopogon refractus	herb	0.21	1	0.04	1	positive diagnostic
Cheilanthes sieberi subsp. *sieberi*	fern	0.57	1	0.23	1	uninformative

There were 89 plots in Floristic Group 5. The mean species richness for a 0.04 ha plot in this group was 34 ± 1. The lowest richness was 17 taxa in plot TC113 and the highest 69 taxa in plot TC047.

Floristic Group 6

The dominant and most characteristic species of Floristic Group 6 is *Cadellia pentastylis* (Table 11; Figures 16 & 17), which occurs in all plots of the Group and at a median C/A of 4 (cover-abundance 20–50%). Other common tree species include *Notelaea microcarpa* var. *microcarpa*, *Elaeodendron australe* and *Geijera parviflora*. The most common shrubs are *Pimelea neo-anglica*, *Solanum parvifolium*, *Spartothamnella juncea* and *Beyeria viscosa*. Vines are not as frequent as in the other floristic groups, although the most common species are *Pandorea pandorana* and *Cayratia clematidea*. The most common herbs are *Austrostipa verticillata/A. ramosissima*, *Carex inversa*, *Poa labillardieri* var. *labillardieri* and *Wahlenbergia luteola*.

Table 11. Diagnostic species of Floristic Group 6.

Species	Growth form	Target frequency	Target CA	Residual frequency	Residual CA	Fidelity class
Cadellia pentastylis	tree	1.00	4	0.01	5	positive diagnostic
Notelaea microcarpa var. *microcarpa*	tree	0.88	2	0.95	3	frequent
Elaeodendron australe	tree	0.55	1	0.39	3	uninformative
Geijera parviflora	tree	0.55	1	0.63	3	uninformative
Alstonia constricta	tree	0.48	1	0.24	1.5	uninformative
Capparis mitchellii	tree	0.48	1	0.34	1	uninformative
Eremophila mitchellii	tree	0.27	2	0.05	1	positive diagnostic
Pimelea neo-anglica	shrub	0.67	2	0.39	1	positive diagnostic
Solanum parvifolium	shrub	0.64	2	0.49	1	positive diagnostic
Spartothamnella juncea	shrub	0.64	1	0.70	2	uninformative
Beyeria viscosa	shrub	0.61	3	0.38	2	positive diagnostic
Abutilon oxycarpum	shrub	0.48	3	0.48	1	positive diagnostic
Einadia hastata	shrub	0.39	2	0.20	1	positive diagnostic
Phyllanthus subcrenulatus	shrub	0.39	2	0.17	1	positive diagnostic
Cassinia laevis	shrub	0.30	1.5	0.03	1	positive diagnostic
Pandorea pandorana	vine	0.48	2	0.78	2	frequent
Cayratia clematidea	vine	0.39	1	0.18	2	uninformative
Austrostipa verticillata/A. ramosissima	herb	0.45	3	0.67	1	positive diagnostic
Carex inversa	herb	0.45	3	0.24	2	positive diagnostic
Poa labillardieri var. *labillardieri*	herb	0.36	3	0.01	3	positive diagnostic
Wahlenbergia luteola	herb	0.33	2	0.01	1	positive diagnostic
Eragrostis megalosperma	herb	0.24	3	0.02	1	positive diagnostic
Aristida caput-medusae	herb	0.12	4.5	0	0	positive diagnostic

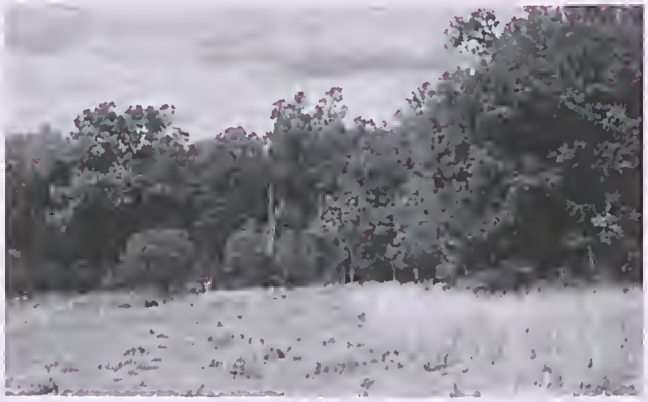


Fig. 16. *Cadellia pentastylis* low microphyll vine forest (Floristic Group 6) on the lower slopes of a low, sandstone hill at "Tara" near Warialda. The canopy is dominated by *Cadellia pentastylis,* while the silver-leaved ironbark *Eucalyptus melanophloia* is an occasional co-dominant.

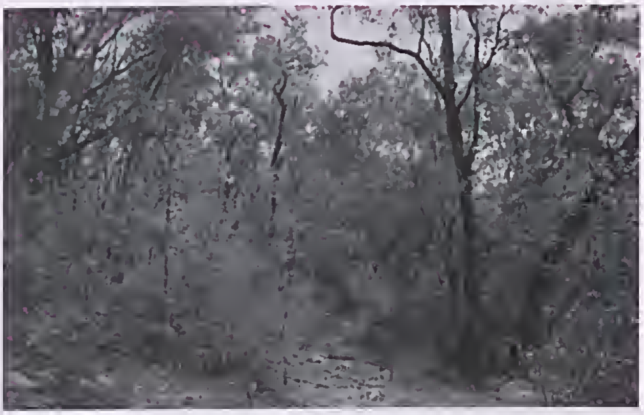


Fig. 17. Interior of *Cadellia pentastylis* low microphyll vine forest (Floristic Group 6) on the lower slopes of a low, sandstone hill at "Tara" near Warialda. The density of the canopy in this community is variable, from open canopy such as in this part of the stand, to closed canopy, as in Figure 16.

There were 33 plots in Floristic Group 6. The mean species richness for a 0.04 ha plot in this group was 23 ± 1. The lowest richness was 11 taxa in plot OOL31 and the highest 35 taxa in plot OOL16.

Structural classification

Floristic groups were readily and unambiguously assigned to Webb structural types based on leaf size classes, proportions of deciduous versus evergreen species and canopy height

(Table 12). Proportions of leaf retention and leaf size classes were similar whether based on proportion of tree species richness or proportion of the importance index. There were generally low proportions of deciduous rainforest trees, usually less than 10%, and sometimes as low as 2%, although 16% (by proportion of importance index) of Floristic Group 5 was categorized as deciduous, due to the abundance of *Ehretia membranifolia* in this community (Figure 15). Two floristic groups (1 and 4) had equal mixes of trees of notophyll and microphyll size classes, Floristic Group 2 comprised two-thirds notophyll leaf classes and one-third microphyll leaf classes, while groups 3, 5 and 6 comprised two-thirds to three-quarters microphyll classes and one-quarter to one-third notophyll classes. There were very low or no nanophyll classes in all groups. Mean height of the rainforest canopy was highest in Groups 2 and 6 and lowest in Group 5. The mean canopy heights of Groups 2 and 6 (>9m) were such that these groups were considered to be vine forest, while the lower heights of the remaining groups (<9m) categorized these as vine thicket.

Distribution

Floristic Group 1 predominantly occurs in the Nandewar (NAN) Bioregion, but also includes some sites in the Brigalow Belt South (BBS) Bioregion and the upper Hunter Valley, including three sites at Mt Dangar near Denman (Figure 18). Sites from Floristic Group 2 and 4 were all restricted to the Hunter Valley, with Floristic Group 4 confined to Brushy Hill, east of Scone. Floristic Groups 5 and 6 were found in the BBS and NAN, while Floristic Group 3 was restricted to Derra Derra Ridge, west of Bingara, in NAN.

Discussion

Floristic classification

The floristic groups of dry rainforest on the western slopes of NSW delineated in this project were broadly similar to those identified by other projects, and largely reflect the groupings predicted from the literature. There was a high degree of concurrence with studies that analysed quantitative plot data (e.g. McDonald 1996; DLWC 2002; DEC 2004a) and generally with those which relied on intuitive classification (e.g. Floyd 1990).

A community dominated by *Cadellia pentastylis* occurring on sedimentary substrates was delineated, as per McDonald (1996), DLWC (2002) and DEC (2004a). This consistency may well be because each of these studies, including the current one, used data from *Cadellia pentastylis* stands collected by Benson (1993). As found by DLWC (2002), not all sites with *Cadellia pentastylis* in the current study were clustered together. Two additional sites were sampled from *Cadellia pentastylis* stands for the current study, both in stands also sampled by Benson (1993). One of these, TC010, clustered with the sites sampled by Benson (1993) in Floristic Group 6, while the other, TC133, was placed in Floristic Group 5. DLWC (2002) described an Ooline Forest floristic group that contained 16 sites. They noted that *Cadellia pentastylis* had a non-target group frequency of 0.01, which in their study equated to 9 sites. The DLWC (2002) study incorporated 16 sites from Benson (1993), but 9 (36%) of their sites from *Cadellia pentastylis* stands (presumably those not sampled by Benson) did not cluster in their Ooline Forest floristic group. Some of these clustered in the SEVT and Dry

Table 12. Webb (1959; 1968; 1978) structural types of each floristic group and the structural variables (leaf retention, leaf size, canopy height) that contribute to this classification. SSENVT=simple semi-evergreen notophyll vine thicket; SSENVF=simple semi-evergreen notophyll vine forest; SEVT=semi-evergreen vine thicket, LMVF=low microphyll vine forest.

Structural features	Floristic group					
	1	2	3	4	5	6
Leaf retention (percentage of tree species /percentage importance index)						
Deciduous	8/2	7/5	11/2	8/3	5/16	7/2
Evergreen	92/98	93/95	89/98	92/97	95/84	93/98
Leaf size classes (percentage number of tree species/percentage importance index)						
Nanophyll	4/1	-	-	8/1	5/2	-
Microphyll	48/61	36/33	67/74	46/47	64/64	73/88
Notophyll	48/38	64/67	33/26	46/52	32/34	27/12
Canopy height (m) mean (standard error)	8.6 (0.5)	13.6 (1.6)	N/A	7.3 (0.5)	6.4 (0.3)	13.2 (1.0)
Webb structural type	SSENVT	SSENVF	SEVT	SSENVT	SEVT	LMVF

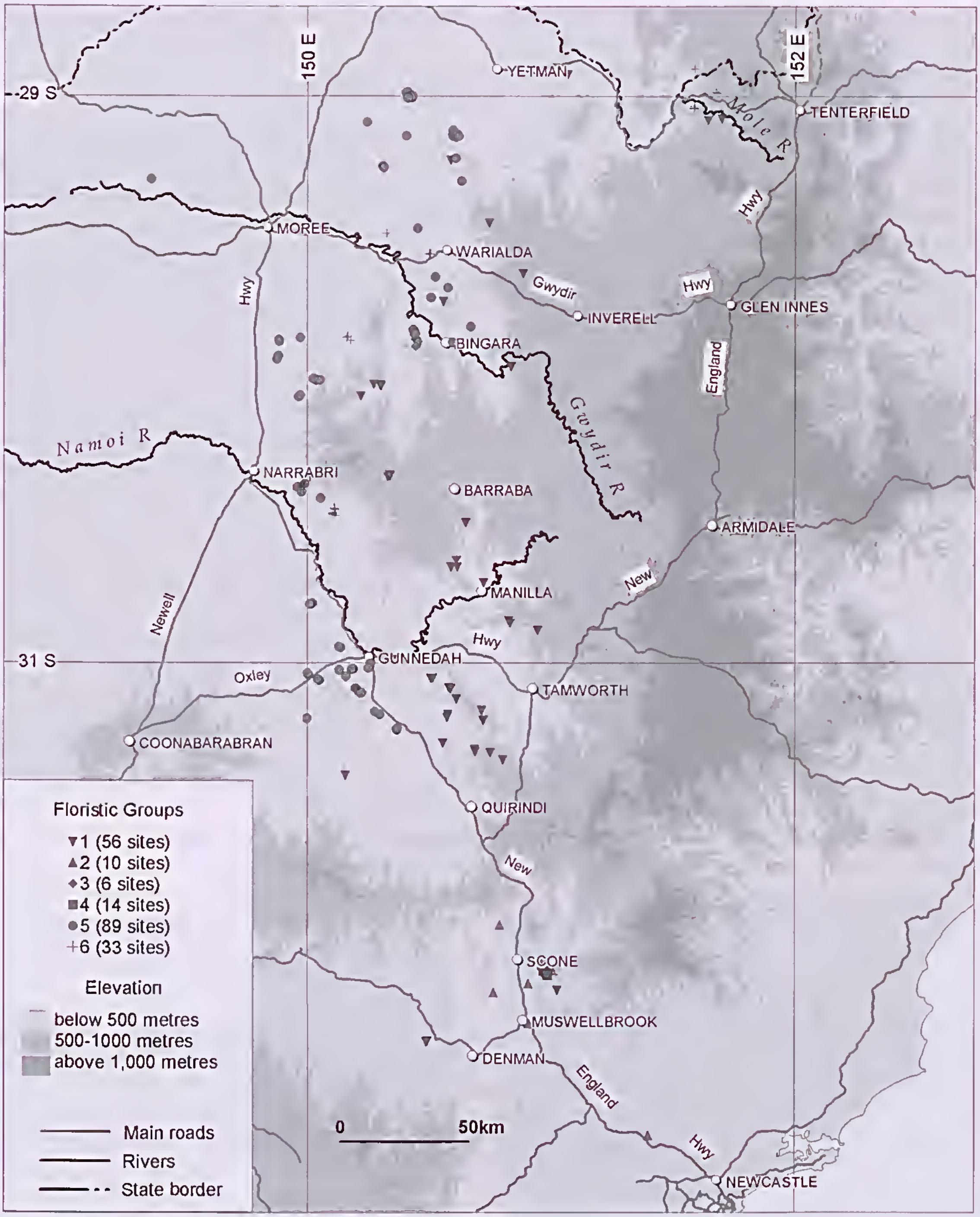


Fig. 18. Location of sites from each floristic group. Base Map data © 2004 Geosciences Australia.

Scrubs floristic group (DLWC 2002). Clearly, there is a need for further investigation of the relationships between plot data from *Cadellia pentastylis* stands collected by different operators.

Floristic Group 1 is similar to the Dry Rainforest floristic group of the Nandewar Ranges delineated by DLWC (2002) and to the Rusty Fig Dry Rainforest and *Alectryon*/Rusty Fig/Mock Olive Dry Rainforest groups identified by DEC (2004a). All these groups are dominated by *Notelaea microcarpa* var. *microcarpa* and *Ficus rubiginosa*, and also share *Alectryon subdentatus* and *Alphitonia excelsa*, and the emergent *Angophora floribunda*. Floristic Group 1 is quite variable in floristic composition and geographic extent and two subgroups broadly equate to each of the two DEC (2004a) groups in both geographic distribution and floristic composition.

An unexpected result was the delineation of two floristic groups of SEVT from the North Western Slopes of NSW. Floristic Group 3 contained only six sites, all sampled by Benson et al. (1996) at Derra Derra Ridge near Bingara, while Floristic Group 5 contained 89 sites sampled by the authors throughout the North Western Slopes, including four plots also sampled at Derra Derra Ridge. There is a high level of dissimilarity between these two groups (Figure 3; dissimilarity >1.3). This may be due to different operators. Collectively, Floristic Groups 5 and 3 equate to the SEVT and Dry Scrub groups of DLWC (2002), the SEVT of DEC (2004a) and the SEVT of McDonald (1996), sharing the same dominant species.

Floristic Group 4 equates to the Hunter Valley Vine Thicket community identified by Peake (2006), reflecting the use of the same data in both studies. Floristic Group 2 includes sites from both the Lower Hunter Dry Rainforest and Upper Hunter Depauperate Dry Rainforest groups of Peake (2006). The merging of these two groups, when analysed in the context of rainforest on the western slopes of NSW, demonstrates the greater similarity they have to each other than to other rainforest stands from the study area.

This project examined for the first time the broader scale relationships between different types of dry rainforest throughout the western slopes of NSW. It demonstrated that the main dichotomy in dry rainforest on the western slopes is between 1) *Ficus rubiginosa*-dominated communities (including those from the Nandewar Bioregion, the Hunter Valley, and to a lesser extent the Brigalow Belt South Bioregion), and 2) the *Elaeodendron australe–Geijera parviflora–Notelaea microcarpa* community of the upper Hunter Valley, the *Cadellia pentastylis* community, and the *Notelaea microcarpa–Geijera parviflora–Ehretia membranifolia* community of the North Western Slopes.

This broad scale dichotomy broadly reflects the distinction between the two vine thicket Suballiances of Floyd (1990); No. 31 *Alectryon forsythii–Alectryon subdentatus–Notelaea microcarpa* and No. 32 *Notelaea microcarpa–Ehretia membranifolia–Geijera parviflora*. All three of the diagnostic species from Suballiance No. 31 are present in Floristic Group 1, although one of the dominant species in this group is *Ficus rubiginosa*, which, while present in some of the stands of Suballiance No. 31 sampled by Floyd, is not a canopy dominant. Another difference is in the varieties of *Notelaea microcarpa*: *Notelaea microcarpa* var. *velutina* is found in Suballiance No. 31 in the Guy Fawkes–Macleay Gorges, while *Notelaea microcarpa* var. *microcarpa* is found on the North Western Slopes. Several of the characteristic species of Floristic Group 2, such as *Alectryon subcinereus*, *Backhousia myrtifolia*, *Geijera salicifolia* var. *salicifolia*, *Cissus antarctica*, *Aphanopetalum resinosum*, *Nyssanthes diffusa*, and *Pyrrosia rupestris*, are also found in Suballiance No. 31 (Floyd 1990).

Floristic Groups 3, 4, 5 and 6, which are all on the lower part of the first dichotomy in the dendrogram (Figure 3), collectively equate to suballiance No. 32 of Floyd (1990). This suballiance included stands of *Cadellia pentastylis* forest, vine thickets from the upper Hunter Valley and vine thickets from the North Western Slopes. A notable exception to this support for the intuitive classification of Floyd (1990) is the stand at Mt Dangar (floristic sites GNG056–058). Floyd placed the Mt Dangar stand in suballiance No. 32, whereas the quantitative analyses conducted in the current study clustered the Mt Dangar sites in Floristic Group 1. Based on the predominance of *Ficus rubiginosa* in these stands, the classification of Mt Dangar vine thicket in Floristic Group 1 seems the most logical result.

The floristic groups identified in this study are less readily matched with the floristic classification of Australian rainforests by Webb et al. (1984). The sites sampled in the present study, perhaps with exception of some sites from the Hunter Valley, are located within the C_2 ecofloristic province of Webb et al. (1984), which is characterized by stands of SEVT and a subtropical (mesotherm/megatherm), moderately seasonal, subhumid climate. Samples from near Gunnedah and from the upper Hunter Valley were used by Webb et al. (1984) to classify rainforest stands using numerical analysis of tree species presence/absence data. Despite the geographic and structural overlap, there is only limited affinity with the list of ten diagnostic species of the C_2 province. Of these ten species, which represent the most common tree species found in the province (Webb et al. 1984), only two, *Alstonia constricta* and *Cadellia pentastylis*, are found in the stands sampled on the western slopes of NSW. Floristic Group 6 is best matched to the C_2 province, having both these taxa as positive diagnostic species. Floristic Groups 1, 3 and 5 all have *Alstonia constricta*, but at low frequencies, while Groups 2 and 4 have neither species. Fensham (1995) also sampled stands in the C_2 province, and encountered all of the diagnostic species of Webb et al. (1984) except *Cadellia pentastylis*, but pointed out that, due to sparse sampling, the Webb et al. scheme did not represent the floristic variation in dry rainforest in inland North Queensland. Russell-Smith (1991) encountered difficulties in assigning his floristic groups to the Webb et al. typology. Webb et al. (1984) acknowledged the limitations in their scheme for outlying stands away from the "core" area of each province. Given that the core area for the C_2 province is at Biloela in central Queensland, some 500 km north of the northern most sites in the present study, and the sparse coverage of sites used by Webb et al. (1984) in the study area of the current project, this lack of concurrence with the Webb et al. typology is understandable.

Structural typology

Unlike studies elsewhere, there were no problems in assigning floristic groups of rainforest on the western slopes of NSW to the structural classes of rainforest defined by Webb (1978). Russell-Smith (1991) was not able to apply the Webb typology unambiguously to his 16 floristic groups. This may be because of the lesser diversity of leaf size classes in rainforests of the western slopes of NSW; there being only three size classes in western NSW (Table 5) compared to five in monsoon rainforest in northern Australia (Russell-Smith

Table 13. Equivalent and proposed nomenclature of dry rainforest assemblages on the western slopes of NSW

Source	Floristic group 1	2	3	4	5	6
Webb (1978)	SSENVT	SSENVF	SEVT	SSENVT	SEVT	LMVF
Floyd (1990a) Suballiance	No. 31	No. 31	No. 32	No. 32	No. 32	No. 32
DLWC (2002)	Dry Rainforest		SEVT		SEVT and Dry Scrubs	Ooline forest
DEC (2004a)	1) Alectryon/Rusty Fig/Mock Olive Dry Rainforest and 2) Rusty Fig Dry Rainforest		SEVT		SEVT	Ooline Open or Closed Forest
Keith (2004)	Dry Rainforest	Dry Rainforest	Western Vine Thicket	Western Vine Thicket	Western Vine Thicket	Western Vine Thicket
Peake (2006)		1) Upper Hunter Depauperate Dry Rainforest and 2) Hunter Valley Dry Rainforest		Hunter Valley Vine Thicket		
Proposed name	*Ficus rubiginosa*–*Notelaea microcarpa* notophyll vine thicket	*Ficus rubiginosa*–*Alectryon subcinereus*–*Notelaea microcarpa* notophyll vine forest	As for Group 5	*Elaeodendron australe*–*Notelaea microcarpa*–*Geijera parviflora* notophyll vine thicket	*Notelaea microcarpa*–*Geijera parviflora*–*Ehretia membranifolia* semi-evergreen vine thicket	*Cadellia pentastylis* low microphyll vine forest

1991). The lower diversity of leaf size classes means that there is less structural diversity: four structural types on the western slopes of NSW compared to ten types for monsoon rainforest (Russell-Smith 1991), and floristic groups could be readily assigned to one of the four structural types. These four structural types: semi-evergreen vine thicket (SEVT), low microphyll vine forest (LMVF), simple semi-evergreen notophyll vine thicket (SSENVT) and simple semi-evergreen notophyll vine forest (SSENVF), are structurally simple forms, lacking many of the specialized life forms and tall height of other rainforest structural types (Webb 1978). This may also contribute to the satisfactory equilibration of floristic groups with structural types. These outcomes contradict the contention of Russell-Smith (1991) that the problems in applying the Webb typology to monsoon rainforests in northern Australia were due to the inherent structural simplicity of those stands. Russell-Smith (1991) based this argument on the finding by Webb et al. (1976) that the scheme was more effective at classifying stands of greater structural complexity. The results of this study suggest that the scheme can also be effectively applied to very simple stands of rainforest.

The differing dissimilarity levels at which floristic groups were delineated may explain the different effectiveness between this study and that of Russell-Smith (1991) in applying the Webb typology. The current study described floristic groups at a very high level of dissimilarity (dissimilarity index>1.0; Figure 3), as the aim was to describe broad floristic groupings, rather than extensively explore differences at lower levels of dissimilarity. While no indication of levels of dissimilarity are given in the dendrogram presented by Russell-Smith (1991)—most likely due to the type of cluster analysis used (two-way indicator species analysis) which does not include such measures—16 floristic groups were described, which suggests that groups were delineated at lower dissimilarity levels than the current study. If Russell-Smith (1991) had described fewer floristic groups, i.e. delineated at higher dissimilarity levels, he may well have found greater concurrence between floristic groups and structural classes.

There was considerable robustness in the categorization of structural classes. Each floristic group of western slopes rainforest was assigned to the same structural type irrespective of whether proportions of numbers of species of different leaf size classes or proportion of the total importance index of different leaf size classes were used. This robustness has important implications for the nomenclature of these rainforest stands on the western slopes of NSW.

Nomenclature of rainforest assemblages

Current nomenclature (e.g. DLWC 2002; DEC 2004a) uses a mixture of both structural and floristic names. For instance, in most schemes, SEVT (equivalent to Floristic Groups 3 and 5 in this study) is consistently referred to by its structural type, whereas other types, e.g. Rusty Fig Dry Rainforest (*sensu* DEC 2004a) or Ooline (*Cadellia pentastylis*) forest (*sensu* DLWC 2002), largely ignore structural classifications and incorporate floristic information. The latter approach is based on the use of vernacular names which incorporate key components of the vegetation and habitat to help readers visualize floristic groups (Keith and Bedward 1999). However, such a scheme should be applied consistently, incorporating such information for all communities.

In an attempt to provide consistency in the nomenclature of rainforest communities on the western slopes of NSW, the following options, with their equivalents from other studies, are proposed (Table 13). The proposed community names include both floristic and structural information on the groups, thus providing a useful guide to the floristic composition, functional attributes (predominant leaf size class) and structure (height) of each group. It is recognized that this nomenclature may be of limited use in conveying visual images of the communities to lay audiences, for instance, Ooline Forest is a much more succinct and evocative description of Floristic Group 6 than *Cadellia pentastylis* low microphyll vine forest. However, the most widely used equivalent of Floristic Group 5, SEVT, is also difficult to explain to lay audiences. Given that it is not possible to derive simple names for each floristic group it was felt that the names should 1) be consistent in their derivation, and 2) convey useful botanical and ecological information. With a little patience and some explanation of the terms, these names could be used for lay audiences and they certainly should be logical, and, importantly, able to be applied consistently to other stands by ecologists and botanists.

Fensham (1995) mounted an argument for dispensing with the term "vine thicket" in favour of dry rainforest on the grounds that 1) people introduced to the former term for the first time envisaged thickets of exotic vines; and 2) that the minimum height for forest under the Specht (1970) structural scheme was 5 m, a height usually attained by the canopy in most stands Fensham sampled. His experiences match those of one of us (TJC) in referring to vine thicket for the first time to several lay people (and some horticulturalists). While Fensham's (1995) view that dry rainforest would be an appropriate general term for the rainforests of the dry tropics and sub-tropics of eastern Australia is supported, the term vine thicket was found to be useful in describing structural features and highlighting the diversity of dry rainforest types on the western slopes of NSW, by helping to distinguish different communities.

Distribution in New South Wales

Elements of this study can be used to describe the limits to the distribution of inland NSW. Dry rainforest communities, with floristic similarities to those described from NSW, particularly SEVT, are found further north in inland Queensland (McDonald 1996). To the east, the high elevation plateau of the Great Dividing Range (Figure 18) provide a barrier to the occurrence of rainforest, most likely due to very low minimum temperatures (King 1980), with the nearest rainforest on the upper reaches of gorges 20 km to the south-east of Armidale (Suballiance No. 31; Floyd 1990).

There are some small stands of dry rainforest to the west of the study area, for instance on scree slopes of the Warrumbungle Mountains, 40 km west of Coonabarabran (Figure 18). These are dominated by *Ficus rubiginosa* and would likely be placed in Floristic Group 1. However, further north and to the west of the Warrumbungles there are no similar steep slopes with such topographic refugia. Also to the west of the study area, the mean annual rainfall steeply declines below 500–600 mm, which is the recognised arid climatic limit for rainforest in North Queensland (Fensham 1995) and the Northern Territory (Russell-Smith 1991). Despite the occurrence of basalt-derived loams further west, which may compensate for lower rainfall (Curran 2006), it appears that there is simply not enough rainfall, nor the topographic refugia, to support rainforest further west in NSW. The outlying site to the west of Moree (TC125; Figure 18), sampled because it was identified as SEVT by Cooper and McAllan (1999), was placed in Floristic Group 5, but was quite dissimilar to other sites in this group. While it had some species common to this group (e.g. *Ehretia membranifolia* and *Geijera parviflora*), there were also species more characteristic of western plains communities, not found in other sites. Consequently, it likely represents a different community, with some affinities to dry rainforest, but representing a transition to more arid vegetation, perhaps part of the "rainforest-derived genera woodlands and shrublands of the inland slopes and plain" vegetation formation of Benson (2006).

The reason for the southern limit is less clear, although the dry rainforests in the study area represent the most southerly stands west of the Great Dividing Range in NSW. With increasing latitude from the study area, rainfall shifts from a summer predominance to equal and then winter predominance. Within SEVT on the North Western Slopes there is a general decline in the richness of trees (TJC pers. obs.) with increasing latitude. While some species which are canopy dominants in SEVT, such as *Notelaea microcarpa* and *Geijera parviflora* do occur further south, few of the other dominants do. So there may not actually be a clear threshold beyond which rainforest does not occur; rather it may be a simple loss of canopy trees to be replaced by more open eucalypt woodlands further south. Adam (1992) noted that in northern Australia there were more rainforest taxa interspersed in surrounding vegetation than in south-east Australia, and implicated lower temperatures and less predicable rainfall in the latter region. This could explain the reduction of rainforest trees with increasing latitude and perhaps the lack of inland rainforest further south than the study area.

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Defining the original extent and floristic composition of the naturally-treeless grasslands of the Liverpool Plains, North Western Slopes, New South Wales

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Abstract: A study was conducted on the Liverpool Plains (30° 43'–31° 44'S; 149° 40'–150° 41'E), North Western Slopes of NSW, to determine the original boundaries of the naturally-treeless grasslands, to determine reasons for the lack of woody vegetation on these areas, and to assess the status of *Austrostipa aristiglumis* (Plains Grass), a species that is today commonly dominant on the few remaining remnant grassland areas and is commonly assumed to characterise the original grassland community. The original tree line boundaries were reconstructed using NSW Lands Department survey portion plans and other historical records. The lack of woody vegetation was attributed primarily to a combination of fine-textured soil, climate and topography restricting the availability of water below the grass root zone, with waterlogging and deep soil cracking possibly playing minor roles. Published and anecdotal evidence and landholder experience indicate that the *Austrostipa aristiglumis* dominated remnants are probably a relatively recent anthropogenic feature, a consequence of post-settlement management practices. The pre-settlement grasslands appear to have been composed of a wide range of grasses, possibly dominated by species such as *Themeda avenacea* (Native Oatgrass) and *Eulalia aurea* (Silky Browntop), with a range of forbs occupying the interstitial spaces. Management implications are discussed.

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Introduction

The Liverpool Plains are located on the North Western Slopes botanical sub-division of NSW and are one of the five main regions in NSW where extensive tracts of naturally-treeless grasslands occurred prior to European settlement (Benson 1996). The Plains were discovered and named by the explorer John Oxley in 1818 and are part of an important and rich agricultural region. However, intensive grazing and cultivation, together with clearing of adjacent woodlands, have impacted on the grasslands, reducing their extent, and masking their original boundaries. Concerns about threats to the grasslands, including coal mining, have led to calls for a conservation strategy for grassland remnants (Urwin 1981, Sim & Urwin 1984). Partly in response to this, the native vegetation on cracking clay soils of the Liverpool Plains of NSW has been listed as an Endangered Ecological Community under the NSW *Threatened Species Conservation Act (1995)* and nominated for listing under the Federal *Environmental Protection and Biodiversity Conservation Act (1999)*. Carter et al. (2003), in their general assessment of the definition, identification and status of Australian Natural Temperate Grasslands, recently estimated that < 10% of the pre-European extent of the Liverpool Plains grasslands remains, and that their survival is threatened.

Community concerns about salinity, biodiversity, dieback and agricultural sustainability, coupled with government vegetation reforms, have focused attention on the management of the nation's native vegetation, soil and water resources. The development of sound management strategies needs to be based on good science including an adequate understanding of the impacts of European settlement on vegetation, soil, biodiversity, and landscape ecosystem function. Vegetation is of special importance because of its use as a surrogate for biodiversity (Smith 2001).

The development of catchment management strategies for remnant areas of the Liverpool Plains natural grasslands requires that the original grassland boundaries be identified and that reasons for the existence of the grasslands be understood. Also, as many grassland remnants are currently dominated by *Austrostipa aristiglumis* (Plains Grass), a species that is widely assumed to characterise the original grassland community (eg. Sim & Urwin 1984, Carter et al. 2003), in spite of evidence that the grasslands of temperate Australia have been profoundly affected by European settlement (Moore 1970, Lodge & Whalley 1989), the status of this grass needs to be clarified.

This project was undertaken to (i) identify and map the original boundaries of the naturally-treeless grasslands of the Liverpool Plains, (ii) to determine the driving processes for treelessness, (iii) to determine the original composition of the grasslands, and (iv) to obtain a preliminary understanding of grassland dynamics, especially the impact of European settlement on species composition.

Study Area

The Liverpool Plains (lat. 30°43'–31°44'S; long. 149°40'–150°41'E) lie on the North Western Slopes of NSW within the catchments of Coxs Creek, the Mooki River and the Namoi River, between its confluence with the Peel River and Boggabri (Fig. 1). They consist of a series of loosely connected alluvial basins separated by low ridges and hills, and bounded in the south by the Liverpool Range, in the east and north by the Melville and Nandewar Ranges, in the west by the Warrumbungle Range and Pilliga Scrub, a total area of about 800 000 ha. It has been estimated that about 260 000 ha were naturally treeless prior to European settlement (Sim & Urwin 1984).

The alluvial basins, on which most of the naturally-treeless grasslands are thought to have occurred, consist of thick, predominantly basalt-derived unconsolidated Quaternary deposits of < 2% slope gradient. The intervening low ridges and hills, which are thought to have been mostly timbered, consist primarily of strongly weathered and eroded Jurassic and Triassic sandstone and conglomerate sediments, some of which are capped with younger basalts. Volcanic intrusives occasionally project above the alluvia as typically isolated conical hills. The southern hilly to mountainous Liverpool Range was formed from Tertiary basalt flows (Offenberg 1971), while the Melville and Nandewar Ranges to the east and north are composed of mixed sedimentary, metamorphic and volcanic rocks of Devonian to Tertiary ages (Offenberg 1971, Brown et al. 1973). The Warrumbungle Range and Pilliga Scrub to the west are composed of Garrawilla Volcanics and Jurassic age Pilliga and Purlawaugh sediments (Offenberg 1968).

Soils are variable depending on geology and depositional sequence. The alluvial soils are mostly deep fine-textured clays, predominantly Black, Grey or Brown Vertosols (Banks 1995, 1998, 2001 & McInnes-Clark 2002). The hill soils are dominated by Black or Red Vertosols, Chromosols or Tenosols, depending on geology.

The climate is sub-humid with warm to hot summers and cool to mild winters. Average annual rainfall varies from about 550 mm in the centre of the Plains to over 750 mm in the south, on the foot slopes of the Liverpool Range (Bureau of Meteorology 1966). Average rainfall on top of the Liverpool Range is > 950 mm/yr (Banks 1998). Although about two thirds of the annual rainfall is received during the summer months from October to March, rainfall is variable with drought and floods likely to occur in any season.

Methods

Mapping the original boundaries of the naturally treeless grasslands

A range of historical documents and maps were used to construct a map showing the original tree-line boundaries of the Liverpool Plains naturally-treeless grasslands. To do this the area was divided into three main areas.

For an area of about 465 000 ha west of the Mooki River, a 1:400 000 scale map (Fig. 2) of the tree-line boundaries by T.K. Abbott (1880b), and apparently derived from earlier NSW Lands Department surveys, was used as a base map. Using this map as a guide, NSW Lands Department 1:15 000 scale survey portion plans (held in the Lands Dept Plan Room, Sydney) were examined. A strategic one-third (due to time constraints) of the plans that contained tree-line boundaries were selected, and tree-line boundaries transcribed to 1:25 000 to 1:30 000 Parish maps, for later desk and field verification. A small sub-sample of the selected portion plans was photocopied for later detailed field verification. Criteria for sub-sample selection were that (i) the tree-line boundaries occurred in areas where little or no clearing was known, or thought to have occurred and (ii) the tree-lines coincided with public roads (for ease of access).

For the headwaters of the Mooki River between Werris Creek and Blackville, an area of 100 000 ha, tree-line boundaries were obtained from the Australian Agricultural Company (AAC) survey maps and historical documents (located in the Noel Butlin Archives Centre, ANU, Canberra). This AAC land had been taken up in the early to mid 1800s and, due to the lease agreement, no government surveys were undertaken.

For the remaining 235 000 ha, the lower catchment of the Mooki River and the Namoi River between Carroll and Boggabri, tree-line boundaries from a strategic selection of most, but not all NSW Lands Department survey plans that contained tree-line boundaries, were transcribed to 1:25 000 to 1:30 000 Parish maps, to complete the composite map and for later verification. A small sub-sample of these portion plans were also photocopied for detailed field verification.

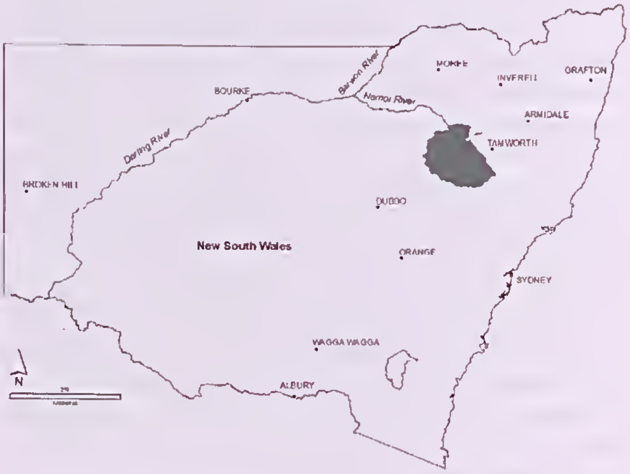

Fig 1. Location of the Liverpool Plains on the North Western Slopes of New South Wales.

For all three areas, the location of tree-line boundaries from the Parish maps were compared with pre-1970 topographic maps (1:31 680 scale) and aerial photographs. These maps and photographs pre-date the period of widespread clearing of timber in the 1950s and 1960s when the introduction of large machinery made cultivation of the heavy clay soils practical. The journals of the early nineteenth century explorers John Oxley, Allan Cunningham and Thomas Mitchell were used to confirm areas of grasslands and woodlands where appropriate.

Field verification of tree-line boundaries on the photocopied plans was undertaken by comparing the orientation and distance of tree-lines from key features, such as roads and portion boundaries, with existing tree-lines and corresponding features. The resultant composite map was digitised by the Gunnedah Resource Centre GIS unit using Esri-ArcView 3.

Grassland determinants

The distribution of the Liverpool Plains grasslands was assessed in relation to factors raised in a literature review to identify explanations for the absence of woody vegetation on areas of naturally-treeless grasslands worldwide, and especially Australia. As part of this assessment, the location of the grasslands on the composite map was compared by simple overlay to the Department of Natural Resource's (DNR) < 2% slope terrain map for the Liverpool Plains and Soil Landscape maps for Blackville, Curlewis, Murrurundi, and Tamworth.

Original grassland composition

Literature was reviewed for information on the botanical composition of the Liverpool Plains grasslands and similar nearby areas. Evidence for floristic changes and possible reasons for such changes over time were noted.

Survey of roadside reserves and landholder interviews

To obtain preliminary information on grassland dynamics a survey of seven roadsides (Pine Cliff, Trinkey Forest, Grain Valley, Melrose, Maxwell, Crisps and Wean Roads) in the central and northern Liverpool Plains was conducted during the period 2005–2006. This aimed to locate colonies of the grass *Eulalia aurea* (Silky Browntop), selected because

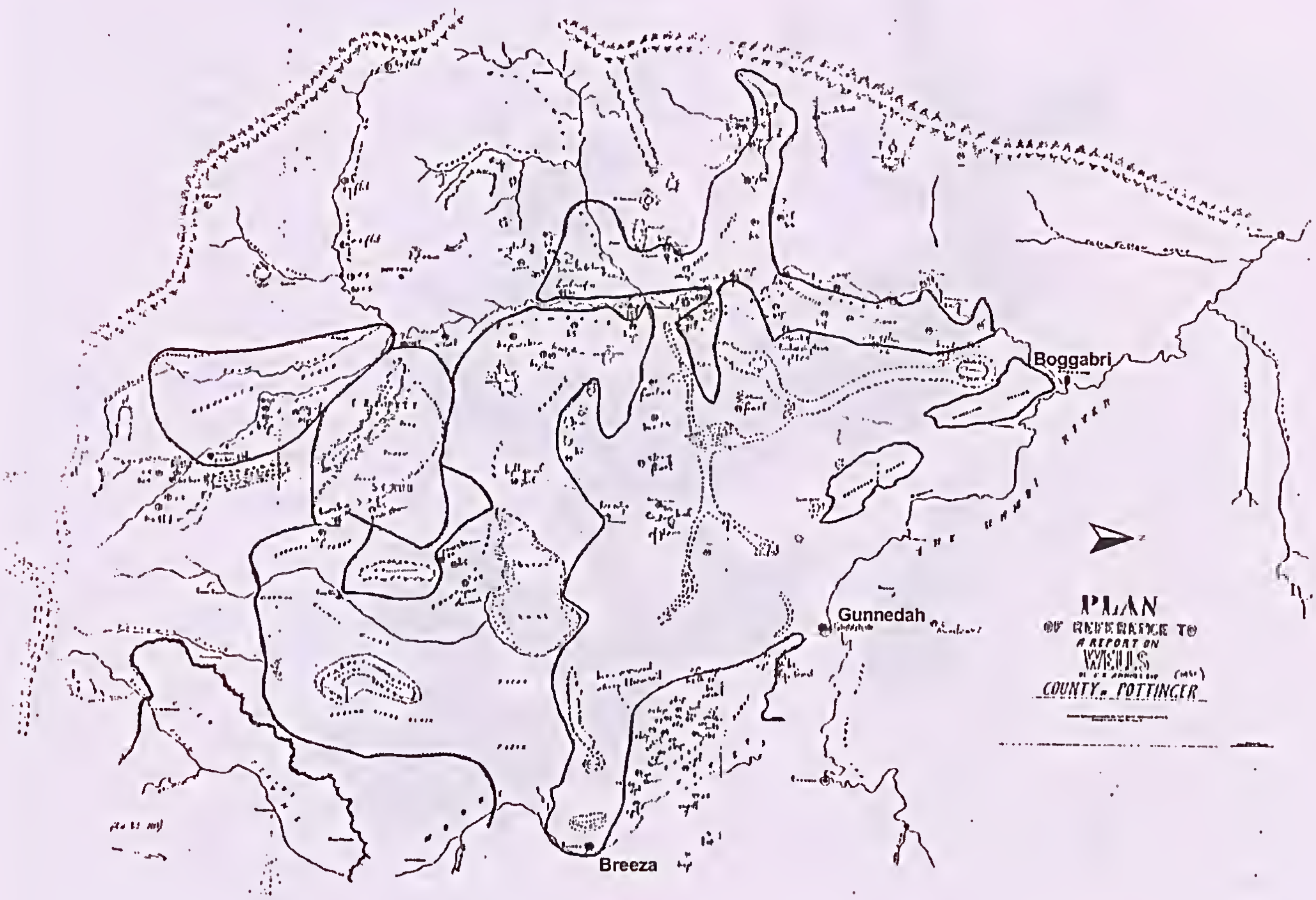

Fig. 2. Tree-line boundaries of the Liverpool Plains naturally-treeless grasslands west of the Mooki River as detailed on the "Plan of Referenee to a Report on wells" by T.K. Abbott (1880b) "On Wells in the Liverpool Plains".

evidence previously collected indicated that (a) this species was previously much more abundant on the Plains than it is now, (b) it may have been a co-dominant species, at least on the northern Plains, (c) its abundance has been increasing on roadside reserves during the last 10–30 years, apparently following the introduction and widespread use of motorised stock transport and consequent changes in grazing pressures, and (e) newly established plants appeared to increase in size with time gradually forming large tussocks and thereby providing an opportunity to identify whether colonies of this plant are increasing, stable or declining.

The diameters of a random selection of plants and tussocks were counted at 1 m intervals along either a linear transect or along radii from a central plant or tussock, depending on the size of the stand. At least 10 plants and tussocks were measured per transect except, however, for very small colonies, ie, < 1 m diameter, when all plants were measured. In addition, the diameters of 10 randomly selected large tussocks were measured in a stand known to be at least 12 years old on the northern Plains property "Mallee Springs".

Landholders who had observed changes to grassland pastures containing key species, such as *Themeda avenacea* (Native Oatgrass), *Eulalia aurea*, *Astrebla lappacea* (Curly

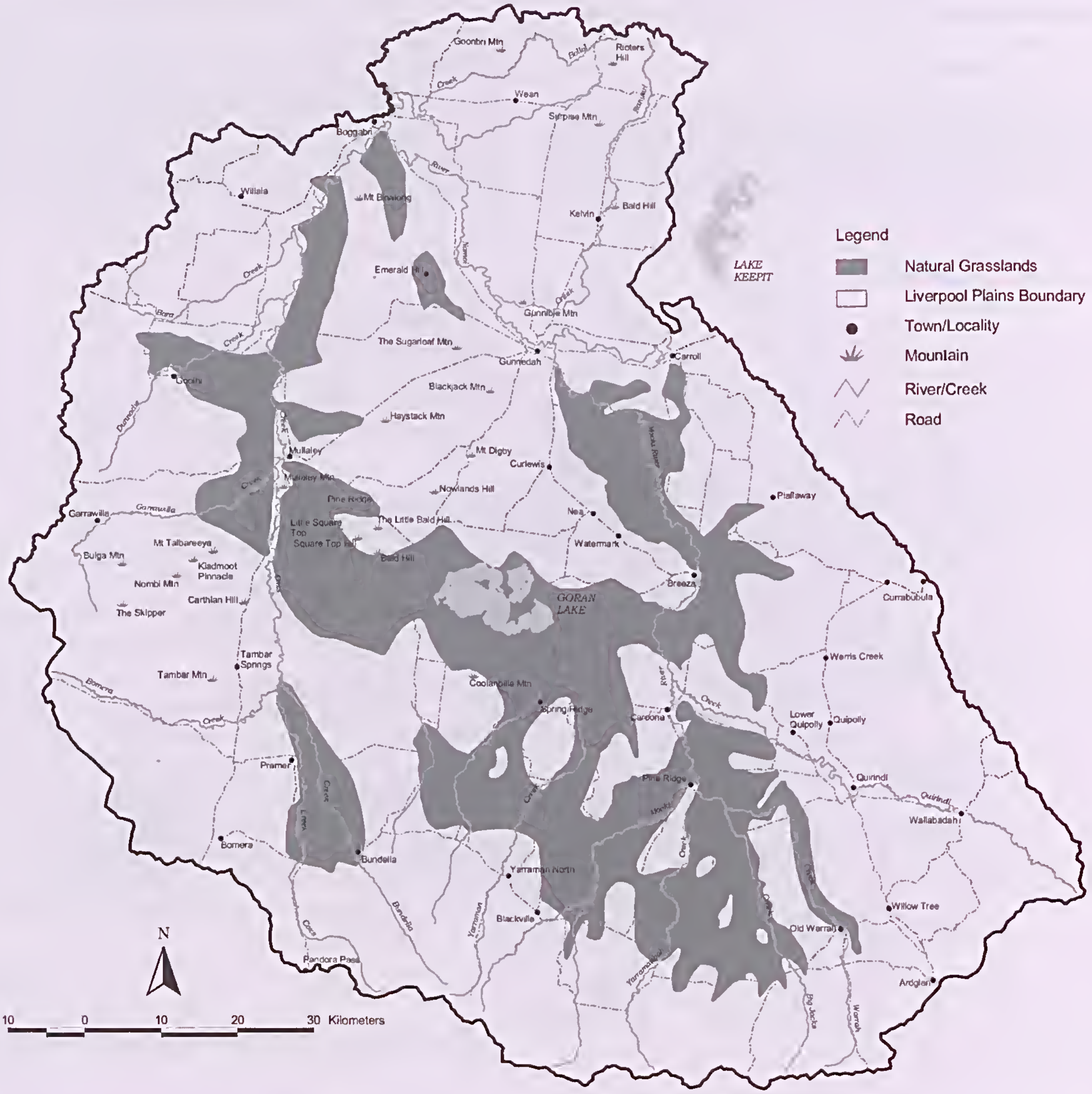

Fig. 3. Reconstructed original distribution of the naturally-treeless grasslands on the Liverpool Plains, NSW.

Mitchell grass), *Dichanthium sericeum* (Queensland Bluegrass) and *Austrostipa aristiglumis*, following changes to grazing management practices were interviewed and their observations noted.

Results

Mapping the original boundaries of the naturally-treeless grasslands

The reconstructed boundaries of the naturally-treeless grasslands of the Liverpool Plains are shown on Fig. 3. For the region west of the Mooki River, tree-line boundaries were transcribed from 306 Lands Dept portion plans, while for the region east of the Mooki River, excluding the AAC holding, boundaries from 277 plans were transcribed. These represented about one third and two thirds, respectively, of the plans that were estimated to document tree-line boundaries. The earliest plan sighted was dated 1839, while the latest plan was dated 1918. Most plans were dated from 1864 to 1885.

Three AAC survey maps were examined, an 1832 map (Deposit 1/452C/2) drawn by surveyor Henry Dangar, a map (78/1/17, p718) accompanying an AAC Report (King 1842) and an 1894 AAC Warra Estate survey map (Ref: B105).

Tree-line boundaries between natural grassland and woodland were indicated on portion plans e.g. Fig. 4 (Portion 190, Parish of Bando, County of Pottinger, dated 1901) where open level black soil plain and adjacent gum and myall woodlands both north and south of Mt Mullaley are clearly delineated. Where clearing had not taken place and where soil and geological differences were distinct, tree-line boundaries were easily located and identified during field reconnaissance (Fig. 5). However, on low slope gradient alluvia of differing depositional facies and susceptibilities to waterlogging, and where geology was broken and complex, the boundaries between the grassland and woodland were contorted. Scattered individuals or clumps of trees often formed a transition zone between distinct grassland and adjacent woodland (Fig. 6).

Boundary accuracy

The accuracy of the portion plan tree-line boundaries was estimated to be about ± 50 m where tree-line boundaries could be related to key physical features, such as roads and fence lines located on portion boundaries. Where distinctive physical features were not present and where clearing had taken place, the tree-line boundaries were difficult or impossible to locate. The accuracy of tree-line boundaries on both Abbott's 1:400 000 scale map (Fig. 2) and the composite map (Fig. 3) was estimated to be ± 0.5–1 km. Accuracy was greatest where fine-textured soil abutted sharply against coarser material and where the geology was simple. Accuracy was least where transition zones occurred and where geologies were complex.

Grassland determinants

A wide range of publications have addressed the distribution or state of grasslands worldwide, but relatively few specifically considered reasons for the existence of naturally-treeless grasslands. Of most relevance to this study are Cambage (1909), Barnard (1964), Moore (1964 & 1970), Beadle (1981), Walker et al. (1981), Titlyanova et al. (1990), Ripley (1992) and Benson (1994). The general conclusion is that the absence of trees on naturally occurring grassland is due to a complex combination of factors, including climate (rainfall, temperature and wind), topography and soil type. Rarely was one single factor thought to satisfactorily explain the existence of natural grasslands.

Ripley (1992) noted that natural grasslands occur throughout the world on a variety of substrates and landscapes in regions where precipitation ranges from 350 to 800 mm/annum and where periodic droughts occur. Cambage (1909), during an extensive floristic survey of NSW, suggested that the lack of trees on the Monaro Plain in southern NSW could be explained by a combination of low rainfall, cold temperatures, drying summer winds and soil structure. Both Moore (1964

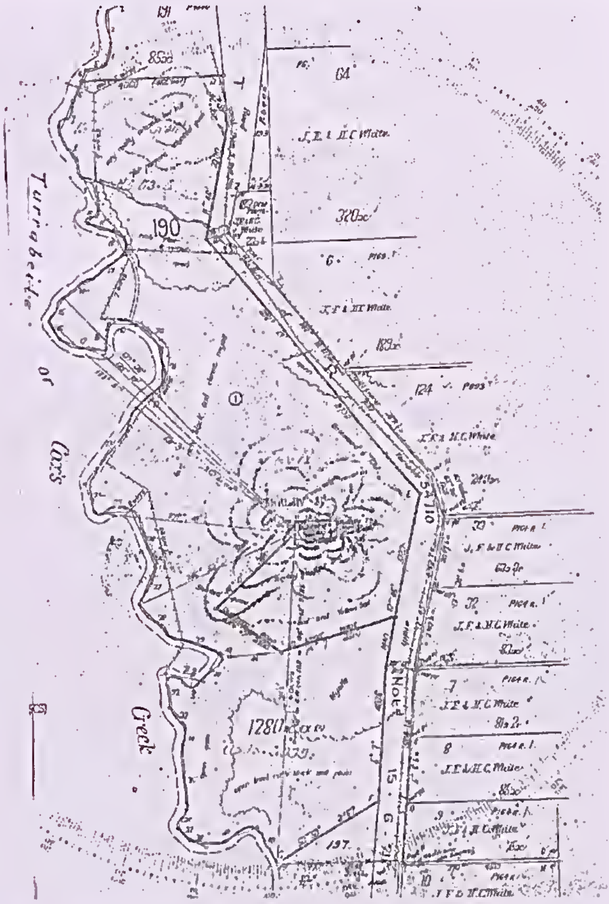

Fig. 4. An example of a surveyor's map, being Portion 190, Parish of Bando, County of Pottinger (dated 1901), showing the tree line boundary between open black soil plain natural grassland and adjacent woodlands around Mt Mullaley.

& 1970) and Benson (1994) recognised the importance of fine-textured soil and restricted soil moisture for Australian grasslands, factors also recognised as important globally by Titlyanova et al. (1990). Walker et al. (1981) were more specific, suggesting that grasses are more efficient than trees in extracting water from the topsoil layer, but that below the grass root zone (typically the subsoil) woody vegetation has nearly exclusive use of whatever water gets through. Beadle (1981) identified five habitats in Australia where one or more environmental factors prevent the development of trees or shrubs, viz. the littoral zone, aquatic and waterlogged habitats, fine-textured soils, the arid zone and frost hollows. Of most relevance to this study is "areas of fine-textured soils, mainly in the semi-arid zone.....where soil texture restricts water-availability, preventing growth of trees, the factor probably acting in conjunction with deep soil cracking or with temporary seasonal waterlogging".

Robbins (1963) considered the factors responsible for the development of derived grasslands during his study of the grasslands of Papua and New Guinea. He attributed their existence to human activity through frequent burning, factors that, together with grazing by domestic stock, are considered responsible for derived grasslands throughout the world (Moore 1964). However, no information was found on the role of aboriginal burning practices in explaining the existence of the Liverpool Plains grasslands. Idriess (2003) and O'Rourke (2005) both provide a detailed account of the life of the Gunn-e-dar tribe (the principal tribe on the Plains) and the Liverpool Plains landscape, but offer little if any information on their use of fire, apart from cooking food. Oxley (1820) noted that parts of the Plains grassland had been previously burnt, but gives no indication that the extent, or nature of the burnt area was unusual.

Comparing the composite map's distribution of the treeless grasslands with DNR's slope terrain and Soil Landscape Maps, together with field reconnaissance, revealed that the grasslands were recorded only on Vertosols where annual average rainfall ranged from 550 mm to about 700 mm and mostly where slope gradients were < 2%. Grasslands were occasionally found on slopes up to 4%, for example

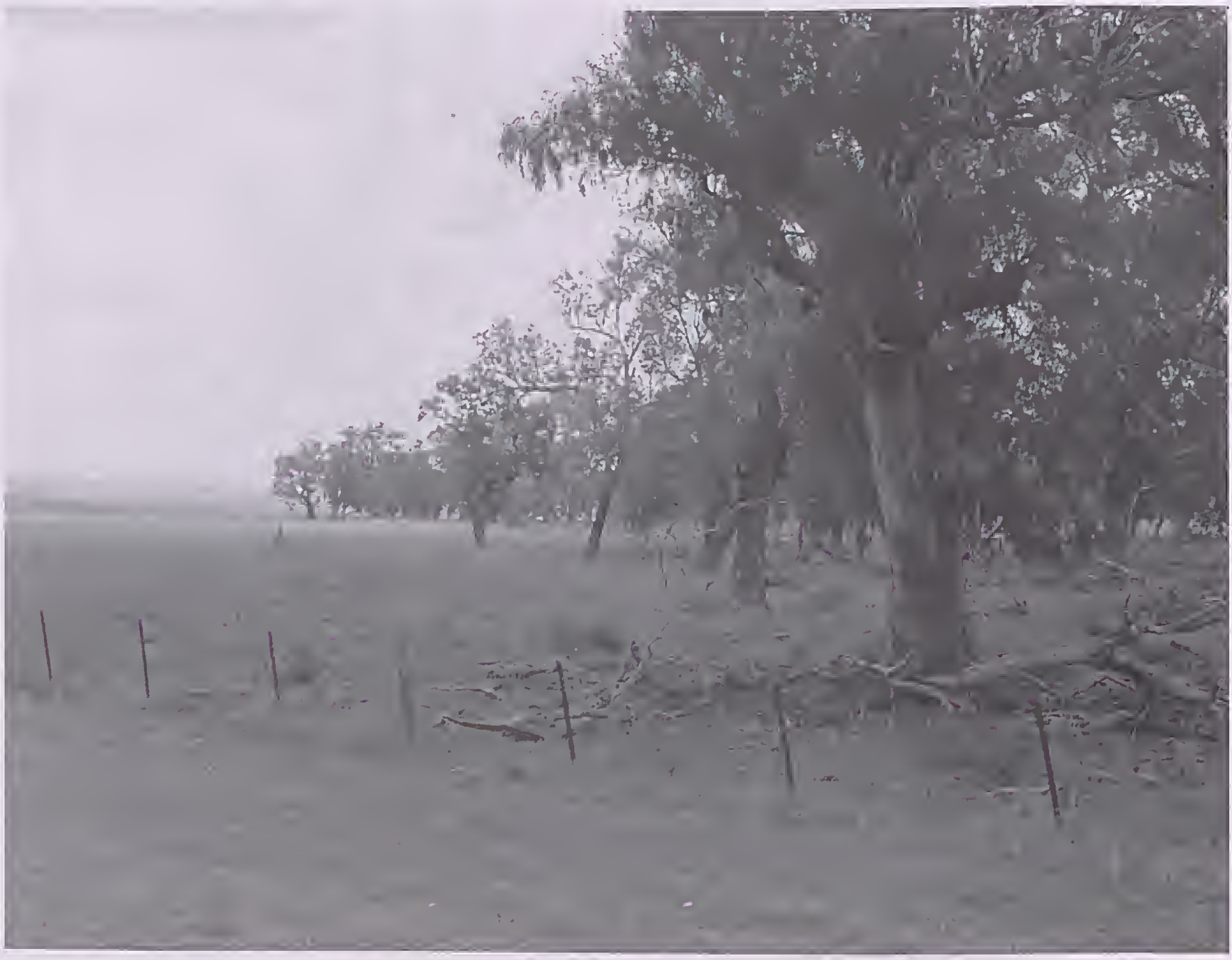

Fig. 5. Distinct tree line boundary between the naturally-treeless grassland of Harrisons Plain and adjacent box woodland on the Harrisons Plain Road.

the southern and south-eastern region of Goran Lake, an area known as the high plain, and on the slopes of volcanic intrusive hill outcrops.

In contrast, woodlands were found on all soil types, rainfall zones and slope gradients. However, trees were found growing on Vertosols only where additional moisture was probably available, such as the higher rainfall slopes of the Liverpool Range, the banks of larger creeks and rivers, and in low landscape situations subject to extended waterlogging. Small ephemeral creeks on heavy clay alluvia were found to be bare of timber.

Original grassland composition

No comprehensive or detailed botanical survey or description of the original vegetation of the natural grasslands of the Liverpool Plains was found. However, scattered references to grassland species and floristic trends on the Liverpool Plains and adjacent areas were found in the journals of early explorers, other historical documents and the scientific literature dating from the time of European settlement to the present. Twenty references were found which identified grassland species on the Plains while ten references were found that made reference to floristic trends following land management changes (Table 1).

Survey of roadside reserves and landholder interviews

Roadside surveys: Nine scattered colonies of *Eulalia aurea* (Silky Browntop), ranging in size from 1 m^2 to 6 400 m^2, were found along four of the seven roadside reserves surveyed (Wean, Melrose, Maxwell and Crisp). The diameter of 188 *Eulalia aurea* tussocks ranged from 1 to 67 cm, with 68% of the tussocks being less than 15 cm in diameter. Locals maintain that these colonies have been expanding during at least the last 10–17 years (K Sheridan, landholder, and D Collins pers. comm.), a period that coincides with stock movement by motorised transport and consequent reduced grazing pressure on the roadside reserves. The diameter of ten tussocks of *Eulalia aurea* known to be more than 12 years old on the property "Mallee Springs" ranged from 35 to 70 cm. Average tussock diameter was 51 cm.

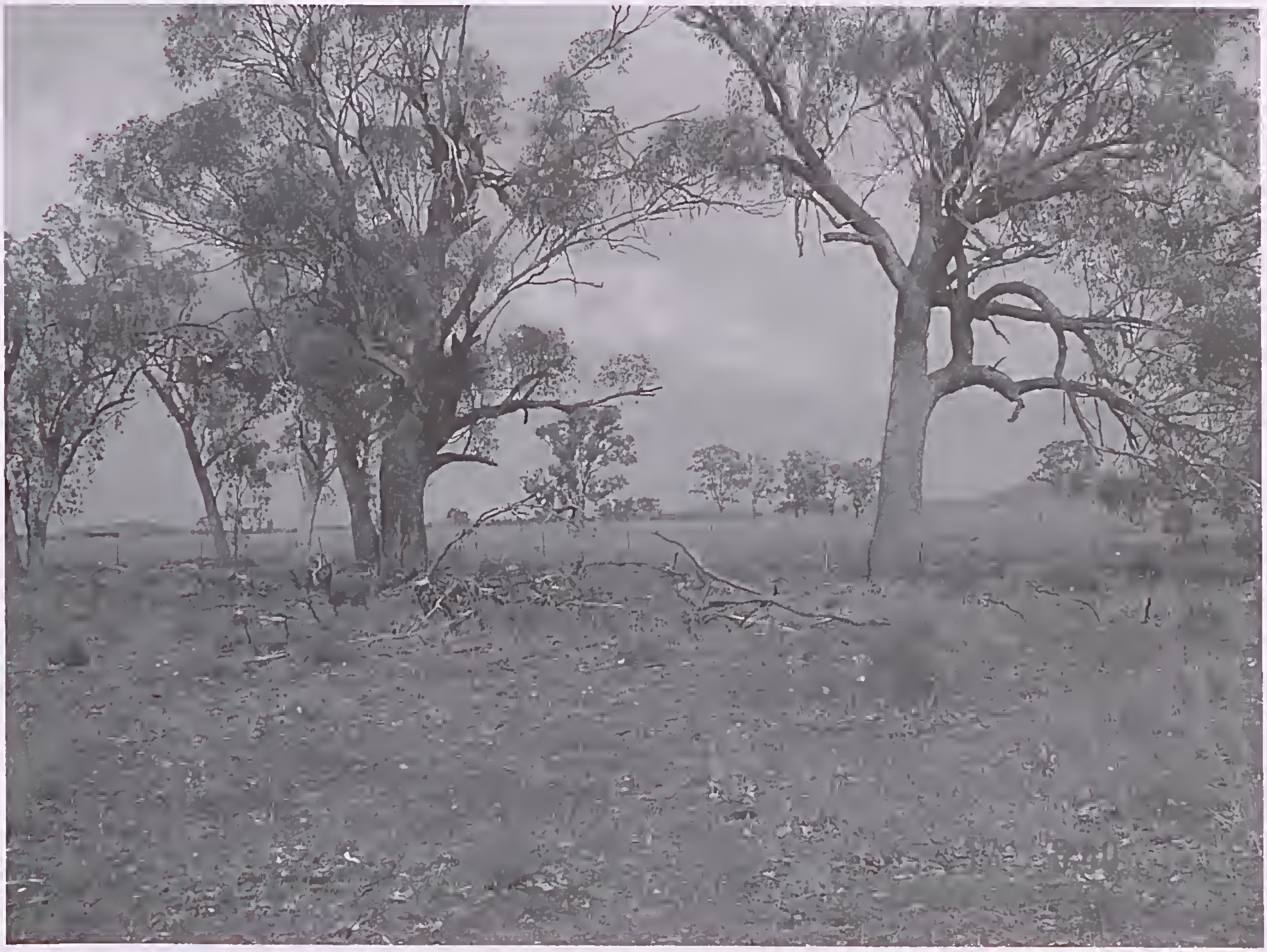

Fig. 6. Transition zone between the naturally-treeless grassland of Colygra Plain and box woodland near the Gunnedah-Boggabri Road.

Landholder interviews: Information was obtained from four landholders on the behaviour of native grasses following changes to their grazing regime during the last 10 years. Anecdotal evidence was collected on the sowing of *Austrostipa aristiglumis* during the late 1800s and on the occurrence of *Astrebla lappacea* (Curly Mitchell Grass) in the early 1900s.

Mr R Frend (pers. comm.) observed that the proportion of *Themeda avenacea* on his central Plains property, "Dimberoy", had increased following the introduction of a rotational cell-based grazing system.

Mr M Payne (pers. comm.) observed that the proportion of *Eulalia aurea* in an *Austrostipa aristiglumis* dominated paddock on his property "Mallee Springs", north of Gunnedah, had increased markedly, from the base of a few plants in the paddock, in the seven year period following the introduction of a rotational crash grazing strategy that specifically mimicked the grazing habit of kangaroos. Visual appraisal in 2004 revealed that *Eulalia aurea* constituted about 60 per cent and *Austrostipa aristiglumis* about 20 per cent of the paddock.

On the property, "Retreat", also north of Gunnedah, small colonies of *Astrebla lappacea* (Curly Mitchell grass) and *Themeda avenacea*, as well as native legumes, in particular *Glycine* spp., have been expanding following the introduction of an intensive rotational grazing system (R Penrose pers. comm.). Long-time residents believe that *Astrebla lappacea* (Curly Mitchell Grass) was common on the Plains in the early 1900s (R Penrose pers. comm.).

A *Dichanthium sericeum* (Queensland Bluegrass) dominated paddock near Colly Blue, on the southern Plains, that for many decades had been intermittently and conservatively grazed (R Banks, DNR Soil Surveyor, pers. comm.) was noted to have been converted to an *Austrostipa aristiglumis* dominated paddock within five years following the introduction of a continuous heavy grazing regime (pers. obs. by author).

Mr J Carter (pers. comm.) understands that his father spread *Austrostipa aristiglumis* (Plains Grass) seed from horseback on the southern Plains property "Yarraman North" during the last half of the 1800s. It was not known why the seed was sown or the condition and composition of the grassland prior to sowing.

Table 1. Historical references to grassland species and floristic trends on the Liverpool Plains and adjacent areas.

Grassland species:

Oxley (1820): Crossed the Plains from west to east but provides very little information on the herbaceous stratum, although he makes frequent reference to lithology, soil and tree species. Mr Evans, a member of the expedition, sketched a view of the Liverpool Plains from a hill looking east over the Mullaley district which shows open grassland and clumps and lines of timber.

Cunningham (in Lee 1923): Descended onto the Plains from Pandora's Pass on May 2, 1825, and described the indigenous vegetation of the land traversed: "a species of Plantago, or rib-grass; Scorzonera sp., or viper's grass; Lotus, or birdsfoot trefoil; Centaurea occidentalis; Ajuga australis, or bugle; Campanula gracilis, or bell-flower; Rumex dumosus, or dock; Galium aparine, or goose-grass; Epilobium, or willow-herb. There were no fewer that eight distinct grasses, among which a late Danthonia gigantea (giant oatgrass resembling wheat on the ear) was most remarkable. Ranunculus lappaceus, Lobelia inundata, Arundo phragmites, and Indigofera sp., a proof of a permanent marsh – were also observed." Unfortunately, Lee (1923) does not indicate whether Cunningham identified the other seven grasses, and Cunningham's original manuscript was not sighted. No mention is made of the location or abundance of these plants.

Nesbit (1831): Described a tall oat like grass, which the colonists referred to as native oatgrass, growing in abundance while assessing the south-eastern Liverpool Plains for the AAC.

Mitchell (1832): provides no useful information on the herbaceous stratum, although he made frequent comments on lithology, soil and tree species.

Bentham (1878): Provides a very early botanical record of the Plains, having collated various early plant collections. Twelve grass species are recorded as having been collected on the Liverpool Plains (Table 2), including Austrostipa (syn. Stipa) aristiglumis, Themeda (syn. Anthistiria) avenacea, Eulalia aurea (syn. Pollinia fulva) and Dichanthium sericeum (syn. Andropogon sericeus). The records do not refer to abundance or whether the species were collected on black or red soils, or on the alluvial basins or intervening hills.

Rev. Mr Boodle (in Galbraith 1988): Described the grassy vegetation growing during the late 1830s on "Collaroy", on the southern Plains: "The grasses consist mainly of barley grass, kangaroo grass, oaten grass. All these grow in tufts".

William Telfer Jr: Telfer, an early settler in the area, described the vegetation on four occasions in his memoirs (in Milliss 1980). Writing specifically about the Liverpool Plains during the mid-1800s: "the splendid herbage on those plains in a good season was something magnificent and the long oaten grass…", of Walhollow Station he wrote: "of the wild oaten variety and a few inches from the ground in the middle of this forrest (sic) of long grass were wild Carrots Crowsfoot and a splendid lot of herbage of all descriptions", on the area from Quirindi to Kicherabel (sic) Station he wrote: "the long oaten grass was fully seven feet high on this (sic) plains at that time".

NSW Lands Department survey plans: Very few references to species were found in these plans. The surveyors rarely identified species in the herbaceous stratum although they often described the soil, at least by colour, documented significant landscape features, and identified tree species. The herbaceous stratum was mostly described in general terms such as "open plains", "well grassed", "poorly grassed" or "barren". Only five of the sighted plans specified the ground flora. Four plans (Plans 105 and 114–116, dating from 1873 to 1883) on the Merrigula Parish map noted an area of "poorly grassed myall scrub" being "with saltbush". Plan No. 166, dated 1918, on the Premer Parish map contained annotations of "no plains grass", "has been cultivated", "with barley grass" and "lucerne".

Turner (1895): An early NSW Department of Agriculture botanist noted that Eulalia aurea (Silky Browntop) and Themeda avenacea (Native Oatgrass) were found in all the Australian Colonies and grew on the "richest of soils".

Turner (1905): Lists 134 native grasses that were present in north-western NSW. He noted that six species of Austrodanthonia (syn. Danthonia), (Wallaby Grass), three species of Astrebla, (Mitchell Grass), Chloris spp. (Windmill Grasses) and species of Eragrostis (Love grasses) were "well distributed over the region" and "prominent amongst the pasture herbage". He also noted that T. avenacea "often grows nine feet high on the black soil plains", and mentioned Austrostipa aristiglumis "growing nine feet six inches high on the Liverpool Plains".

Breakwell (1923): Also an early NSW Department of Agriculture botanist noted that Eulalia aurea was confined mostly to the western districts where it grew "luxuriantly" on the "black soils" of north-western NSW.

McTaggart (1938): In a survey of the pastures of Australia, listed the dominant grasses on the Liverpool Plains as Dichanthium sericeum (Queensland Bluegrass), Austrostipa aristiglumis (Plains Grass), A. scabra (Rough Speargrass), A. setacea (Corkscrew Grass), and Wallaby grasses. He noted a change in the species composition from the northern to the southern portion of the Plains, with the latter species becoming dominant and the others co-dominant. Windmill grasses, Chloris spp. (star grasses) and Themeda australis (Kangaroo Grass) are listed as sub-dominants. He noted that the Plains, particularly the northern Plains, contained similar herbage plants to that which occurred in the southern portion of the Mitchell-Queensland Bluegrass area. Forbs included "trefoil (Medicago spp.), Lamb's Tongue (Plantago spp.), Wild Carrot (Daucus carota), crowfoot (Erodium spp.), Roly Poly (Salsola kali), Rhagodia nutans, and Enchylaena tomentosa".

Moore (1970): Appraised the dry temperate grasslands of southern Queensland, NSW and Victoria and, of the Liverpool Plains, states that "The dry Temperate Grasslands are now Stipa aristiglumis syn. S. bigeniculata (plains grass) and Danthonia spp" . NB: S. bigeniculata is not now considered synonymous.

Williams (1979): Surveyed the natural pastures in the north-western slopes of NSW and found two mutually exclusive sub-associations on the heavy clay alluvium of the Liverpool Plains (i) an almost pure stand of Austrostipa aristiglumis and (ii) a botanically more complex association dominated by Enteropogon acicularis (Curly Windmill Grass), with various sub-dominants. The factors favouring one association or the other were not identified.

Soil Conservation Service District Technical Manuals (Anon. 1975, Anon. 1976, Anon. 1980, Marston 1984): In a general vegetation survey, the naturally-treeless grasslands of the Liverpool Plains were delineated on maps of the vegetation in the Gunnedah, Quirindi, Murrurundi and Coonabarabran District Technical Manuals, together with a list of the grasses found in the grasslands. A "Plains Grass (Stipa aristiglumis) dry tussock grassland" was described on the "heavy-textured cracking clay soils often associated with the flood plains of the major creeks and rivers". Austrostipa aristiglumis was noted to "almost totally dominate the sward in much of the un-disturbed areas of the community". Between three and eight other native grass genera or species, depending on the district, are listed as sub-dominates (Table 3). The composition of the sub-dominants varies with each district. Dichanthium sericeum is listed as a sub-dominant in all four districts, Astrebla lappacea is listed in two districts while Eulalia aurea is listed in one district only. Themeda australis (Kangaroo Grass) is listed in two districts but Themeda avenacea is not listed in any district.

Bean & Whalley (2001): In a study of 16 non-arable remnant native grassland sites in a 72 km2 sub-catchment of Garrawillie Creek, on the western margin of the Liverpool Plains, seven native grassland associations were identified on two rock types. Austrostipa aristiglumis was recorded from four of the associations but was abundant only in one association, the Austrostipa aristiglumis Association, where it dominated (frequency score 8.0) (Table 4). Other native grasses found in this association were Aristida ramosa (4.0), Austrostipa scabra (2.0), Austrostipa verticillata (2.0), Eriochloa pseudoacrotricha (2.0) and Bothriochloa spp (1.0). The Austrostipa aristiglumis Association site is the only site that previously may have been a naturally-treeless grassland or, more likely, to have been closely associated with the adjacent naturally-treeless grassland.

Hosking (unpub. data): Lists 195 native species, including 45 native grasses and 124 native Dicotyledons (including 12 native legumes) as growing on 10 remnant grassland sites in a continuing survey (to January 2006) of the flora of the cracking clay soils of the Liverpool Plains (Table 5). Austrostipa aristiglumis is the only native grass found growing at all 10 sites. Dichanthium sericeum and Cynodon dactylon (Common Couch) were found at eight of the sites while Austrodanthonia bipartita (Wallaby Grass), Enteropogon acicularis, Eriochloa pseudoacrotricha (Early Spring Grass), Lachnagrostis filiformis (Blowngrass), and Panicum queenslandicum (Coolibah Grass) were found at seven. Themeda avenacea was found at three sites, and Eulalia aurea and Astrebla lappacea at one site only.

Floristic trends and other significant landscape changes:

Oxley (1820): During his second trip down the Macquarie River, Oxley commented critically about the destruction occasioned by cattle to waterholes in the few years since his first trip.

Gardner (1854): Expressed concern that the herbaceous stratum over northern and western NSW was severely impacted by stock, stating "sheep runs have affected (sic) great alterations…and pretty nearly swept the grasses clean out of sight, in the space of twenty years from many a luxuriant and lovely spot".

Telfer (in Milliss 1980): Writing about the Galathera Plains, not on the Liverpool Plains but an adjacent Plain near Narrabri, in 1895: "were quite bare of grass and like a desert of black ground a few dry Rolly Polly blowing about the plain with Clouds of dust and hot winds". Telfer compared the Peel River valley at the time of writing (approximately 1900) to his memories of the region in 1851: "is first class plains Country or river flats and overstocking deteriates (sic) the Country destroying the natural Grasses and herbage Causing (sic) a lot of useless weeds to grow in place of it". He compared the "Qirindi (sic) Liverpool Plains" at the time of writing to the region in 1844: "but now there is a lot of noxious weeds growing in place of the natural pasture … when a run is overstocked they destroy the natural grasses there is nothing but rubbish to take its place". On Walhollow Station (Liverpool Plains) he wrote: "in 1858 I saw grass on those plains ten feet high which you dont (sic) see those (sic) days now the Country has been fenced in and overstocked".

Maiden (1898): Noted that "…of overstocking, with the result that the grasses most palatable to stock are temporarily (or perhaps permanently) eaten out, while their place is taken by weeds and inferior grasses – grasses which have spread, because they have been comparatively uninterfered (sic) with by stock".

Turner (1895): Noted that "Overstocking and the rabbit pest…have already had an injurious effect upon some of the natural herbage… the more valuable plants have been so persistently eaten down that they are gradually dying out…many noxious weeds, both indigenous and exotic, bad grasses, and pine scrub are gradually occupying their place".

Breakwell (1923): Commented on Themeda avenacea that "there is still a good deal of it on the Liverpool Plains, but elsewhere it is not nearly as abundant as previously".

Moore (1970): Of the Liverpool Plains, states that "The dry Temperate Grasslands are now Stipa aristiglumis syn. S. bigeniculata (plains grass) and Danthonia spp. Originally Themeda avenacea (native oatgrass) appears to have been at least co-dominate with Stipa but is now found only in areas totally protected from grazing".

Anon. (1975): Noted that when Austrostipa aristiglumis grasslands were cropped they tended to revert rapidly to a Plains grass dominant community once cultivation ceased.

Marston (1984): Noted that disturbance of the grassland by cultivation allowed "other species to invade and dominate, or establish co-dominance with the plains grass".

Lodge & Whalley (1989): Postulated that originally, on the fine-textured soils of the lower northern slopes of NSW, Austrostipa aristiglumis was co-dominant with Themeda australis, Sorghum leiocladum (Wild Sorghum) and Dichanthium sericeum (Queensland Bluegrass). They concluded that the evidence suggested that associated species included Chloris spp., Sporobolus spp., Eulalia aurea, Eragrostis brownii (Brown's Lovegrass), Enneapogon nigricans (Niggerheads) and Panicum effusum (Hairy Panic). They noted that Austrostipa aristiglumis "is only commonly found on heavy textured soils".

Table 2. Grass species collected by Cunningham, Moore, Leichhardt, Stuart and Woolls on the Liverpool Plains and listed in Bentham (1878). Nomenclature follows Wheeler et al. (2002)

Current name	**Species as listed historically**
Alloteropsis semialata	*Panicum semialatum*
Aristida leptopoda	*Aristida leptopoda*
Aristida ramosa	*Aristida ramosa*
Arundinella nepalensis	*Arundinella nepalensis*
Austrostipa aristiglumis	*Stipa aristiglumis*
Capillipedium parviflorum	*Chrysopogon parviflorus*
Dichanthium sericeum	*Andropogon sericeus*
Enneapogon nigricans	*Pappophorum nigricans*
Eragrostis brownii	*Eragrostis brownii*
Eulalia aurea	*Pollinia fulva*
Sporobolus caroli	*Sporobolus lindelyi*
Themeda avenacea	*Anthistiria avenacea*

Table 3. Native grass species from four Soil Conservation Service of NSW District Technical Manuals that describe the naturally-treeless grasslands of the Liverpool Plains.

Dominants	**Sub-dominants**
Gunnedah Technical Manual	
Austrostipa aristiglumis	*Panicum* spp.
[syn. *Stipa aristiglumis*.]	*Dichanthium sericeum* *Chloris* spp.
	Aristida spp.
	Austrostipa spp. [syn. *Stipa* spp.]
	Austrodanthonia spp. [syn. *Danthonia* spp.]
Quirindi Technical Manual	
Austrostipa aristiglumis	*Dichanthium sericeum*
	Chloris truncata
	Themeda australis
	Eulalia aurea [syn. *E. fulva*]
	Eragrostis spp.
	Austrostipa scabra [syn. *Stipa scabra*]
	Astrebla lappacea
Murrurundi Technical Manual	
Austrostipa aristiglumis	*Dichanthium sericeum*
	Chloris spp.
	Panicum spp.
Coonabarabran Technical Manual	
Austrostipa aristiglumis	*Dichanthium sericeum* *Chloris truncata*
	Themeda australis
	Eulalia aurea
	Eragrostis spp.
	Austrostipa scabra
	Astrebla lappacea
	Eriochloa pseudoacrotricha

Table 4. Occurrence of *Austrostipa aristiglumis* and associated native grass species, with mean frequency scores, in grassland Association 7 on a gentle south-east slope on Garrawilla Volcanics (altitude 380 m) in Garrawillie Creek sub-catchment, western Liverpool Plains.

Species	**Frequency score**
Austrostipa aristiglumis[1]	8.0
Austrostipa scabra	2.0
Austrostipa verticillata	2.0
Aristida ramosa	2.0
Eriochloa pseudoacrotricha	2.0
Bothriochloa decipiens/macra	1.0

Associations 1–6 located most likely on previously timbered slopes.
[1] *Austrostipa aristiglumis* was also recorded in:

Association 3 (frequency 0.3), an *Aristida ramosa, Bothriochloa decipiens/macra* and *Dichanthium sericeum* Association on phonolite scree on steeper slopes (altitude 440–460 m),

Association 4 (frequency 0.3), a *Bothriochloa decipiens/macra* Association on Garrawilla Volcanics (altitude 435–440 m), and

Association 6 (frequency 0.5), a *Dichanthium sericeum* Association on very gentle slopes on Garrawilla Volcanics (altitude 410–420 m).

Table 5. Poaceae taxa collected to January 2006 by John Hosking (unpublished data) in his continuing survey of the flora of cracking clay soils of the Liverpool Plains, with number of sites (out of 10) where each species has been found. (Nomenclature follows Wheeler et al. (2002))

Species	**Common name**	**Number of sites**
Amphibromus nervosus	-	2
Aristida leptopoda	White Speargrass	5
Astrebla lappacea	Curly Mitchell Grass	1
Austrodanthonia bipartita	Wallaby grass	7
Austrostipa aristiglumis	Plains Grass	10
A. scabra subsp. *scabra*	Speargrass	1
A. verticillata	-	2
Bothriochloa biloba	-	5
B. macra	Redgrass	1
Bromus arenarius	Sand Brome	6
Chloris truncata	Windmill Grass	6
Cynodon dactylon	Common couch	8
Dactyloctenium radulans	Button Grass	1
Dichanthium sericeum	Queensland Bluegrass	8

Digitaria divaricatissima	Umbrella Grass	3
Diplachne fusca	Brown Beetle Grass	3
Echinochloa colona	Awnless Barnyard Grass	4
Elymus scaber var. *plurinervis*	Wheatgrass	5
Enneapogon nigricans	Niggerheads	1
Enteropogon acicularis	A Curly Windmill Grass	7
Eragrostis leptostachya	Paddock Lovegrass	3
E. parviflora	Weeping Lovegrass	1
Eriochloa crebra	Cup Grass	1
E. pseudoacrotricha	Early Spring Grass	7
Eulalia aurea	Silky Browntop	1
Iseilema membranaceum	Small Flinders Grass	1
Lachnagrostis filiformis	Blowngrass	7
Leptochloa divaricatissima	-	3
Panicum buncei	-	4
P. decompositum	Native millet	5
P. queenslandicum var. *queenslandicum*	Coolibah Grass	4
Paspalidium aversum	-	4
P. constrictum	Knottybutt Grass	1
P. globoideum	Shotgrass	1
P. gracile	Slender Panic	2
P. jubiflorum	Warrego Grass	2
Paspalum distichum	Water Couch	4
Phragmites australis	Common Reed	1
Poa fordeana	-	4
Sporobolus caroli	Fairy Grass	3
S. mitchellii	Rat's Tail Couch	1
Thellungia advena	Coolibah grass	1
Themeda avenacea	Native Oatgrass	3
Tragus australianus	Small Burrgrass	1

Discussion

This study has shown that valuable information can be obtained from a wide variety of sources to assist in reconstructing pre-European vegetation patterns, in assessing subsequent changes in species composition, and in understanding species and community dynamics. However, as Jeans (1978) and Mactaggart et al. (2007) have correctly pointed out, written historical data should be interpreted cautiously and with a clear understanding of their limitations. Similarly, attempts to infer vegetation patterns and ecological relationships from existing vegetation remnants should proceed with caution given the possibility of extensive post-settlement landscape changes for which evidence may have long since disappeared.

Mapping the original boundaries of the naturally-treeless grasslands

Land survey and other historical records were a valuable source of information that enabled pre-settlement vegetation patterns to be reconstructed, and complements the work of Jeans (1978), Fensham & Fairfax (1997), and Martin (2001). However, an interpretation issue of particular concern to this study was the possibility that significant tree clearing may have occurred between initial settlement and subsequent land alienation surveys. The majority of surveys were done during the period 1860–1885, some 30–40 years after occupation; early clearing may therefore not have been recorded on portion plans. Evidence indicates that this is not a serious concern however. Abbott (1880a) states that ringbarking, the most widespread and significant form of clearing at that time, did not commence in the adjacent Hunter Valley until the 1860s, and did not become general until the 1870s. Jeans (1978) found that "drastic intervention", such as ringbarking, was "very often recorded" on the portion plans. In fact, annotations to ringbarking were found on occasional portion plans but only on those dated after the mid-1870s. Thus it seems reasonable to assume that most of the portion plans show the tree vegetation as preceding any widespread clearing, and that the portion plans are most likely to have recorded "drastic intervention" events where these events had occurred.

Grassland determinants

The physical environment (climate, soil and topography) of the inferred naturally-treeless grasslands of the Liverpool Plains corresponds precisely with the factors thought responsible for naturally-treeless grasslands around the globe. In particular, the high water holding capacity of the heavy smectite clay soils (Banks 1995, 1998, 2001 & McInnes-Clark 2002), relatively low rainfall, high evaporation rates and a year-round potential growing season are consistent with the factors outlined by Walker et al. (1981) and Beadle (1981) that explain the existence of naturally-treeless grasslands. The presence of trees on coarse and medium-textured soils, and on Vertosols that most likely experience enhanced water availability, would tend to support the significance of the hydro-edaphic drivers. The widespread occurrence of deep soil cracks and temporary seasonal waterlogging suggest that these factors may also play a role, but the importance of these two factors is unknown and requires further research.

The role, if any, of aboriginal burning practices in creating and maintaining the Liverpool Plains grasslands was not confidently determined because of a lack of evidence. Nevertheless, the consistent association between the distribution of natural grasslands on the Plains and the physical factors commonly associated with treelessness, suggests that aboriginal burning practices may have had little effect on tree-line boundaries.

Original grassland composition

Austrostipa aristiglumis is closely associated with the Liverpool Plains; one of its common names is Liverpool Plains Grass (Sim & Urwin 1984), and both the scientific and local community have often assumed that *Austrostipa* *aristiglumis* characterises the original grassland ecological community (Moore 1970, Sim & Urwin 1984, Carter et al. 2003). Annotations on the Premer Parish Map survey plan No. 166, dated 1918, suggest that by this time at least *Austrostipa aristiglumis* was widespread and conspicuous on the southern Liverpool Plains and that it may have been the dominant species.

However, although many of the grassland remnants on the Plains are currently dominated by *Austrostipa aristiglumis*, this study does not support the assumption that this grass reasonably characterises the original grassland community. In contrast, the evidence suggests that *Austrostipa aristiglumis* has only achieved dominance during the last 100 years or so as a result of heavy and continuous grazing by stock and feral herbivores.

For example, there is an interesting dichotomy between more recent literature and the early literature in the description of the Liverpool Plains grasslands. The more recent literature focuses on *Austrostipa aristiglumis* as a species both dominant in, and characteristic of, remnant grasslands (McTaggart 1938, Moore 1970, Anon. 1975 & 1976, Williams 1979, Anon. 1980, Urwin 1981, Sim & Urwin 1984, Marston 1984, Bean & Whalley 2001, Hosking unpub. data). By comparison, in the early literature (Allan Cunningham in Lee 1923, Nesbit 1831, Boodle in Galbraith 1988, Bentham 1878, Telfer in Milliss 1980, Turner 1895, Turner 1905 and Breakwell 1923) there is a lack of focus on *Austrostipa aristiglumis* and, instead, reference is made to other species. In particular, early writers (Cunningham, Nesbit, and Telfer) refer to a tall, oat-like grass growing abundantly on the Liverpool Plains, a description that fits *Themeda avenacea* (Native Oatgrass) but not *Austrostipa aristiglumis*. Breakwell (1923) specifically refers to the general decline of *Themeda avenacea* in NSW although “there was still a good deal of it on the Liverpool Plains”.

Of relevance, also, is the generally accepted change in the structure and composition of native temperate grassland communities following European settlement in eastern Australia (Breakwell 1923, Moore 1970, Lodge & Whalley 1989). These changes are attributed to the introduction of cloven hoofed animals, widespread serious overgrazing by stock, the devastating explosion in the rabbit population, and drought, the effects being often graphically outlined in a wide range of publications (eg, Oxley 1820, Gardner 1854, Telfer in Milliss 1980, Maiden 1898, Turner 1895, Anon. 1901, Breckwoldt 1988, O’Rourke 2005 – the effect of cultivation on *Austrostipa aristiglumis* grasslands was noted by Anon. (1975) and Marston (1984), but is ambivalent). Also of interest is the reported sowing of *Austrostipa aristiglumis* (Plains Grass) seed from horseback on the Plains during the last half of the nineteenth century. The necessity to sow *Austrostipa* seed tends to indicate that this species was not abundant at that time. Furthermore, observations by R. Banks and this author provide striking contemporary field evidence that a grassland where *Austrostipa aristiglumis* was inconspicuous (*Dichanthium sericeum* dominant) can be rapidly converted to a grassland dominated by *Austrostipa aristiglumis* following the introduction of a heavy continuous grazing regime that typifies the post-settlement grazing regime. That this conversion is reversible, in principle, is demonstrated by the experience of landholders Payne, Frend and Penrose, and the roadside reserve surveys where the key grasses *Themeda avenacea*, *Eulalia aurea* and *Astrebla lappacea*, as well as native legumes, have noticeably increased in abundance in a range of grassland states, including a dominant *Austrostipa aristiglumis* state, following the introduction of grazing regimes that probably mimic pre-settlement grazing by kangaroos, other herbivores, and possibly fire. That this reversal can also be rapid is indicated by the roadside reserve surveys, where the dominance of small *Eulalia aurea* plants and tussocks (68% < 15 cm diameter) suggests not only that the colonies are expanding, but also that, when compared with the 51 cm average diameter for tussocks >12 years old at “Mallee Springs”, the expansion is both recent and rapid. Thus, it seems doubtful that the Liverpool Plains grasslands, now characterised by *Austrostipa aristiglumis*, could have alone escaped the effects of 160 years of intensive overgrazing by introduced stock and rabbits and periods of severe drought without significant floristic change.

The grass *Eulalia aurea*, in particular, is interesting as it is highly palatable, being called “sugar grass” by early stockowners and previously growing “luxuriantly” on “the black soils of the north-west” (of NSW) (Turner 1895, Breakwell 1923). Consequently, it might be expected that *Eulalia aurea* would be highly susceptible to heavy continuous grazing and be replaced by less palatable species such as *Austrostipa aristiglumis*. Conversely, if *Eulalia aurea* was originally abundant on the Plains and possessed a competitive advantage over *Austrostipa aristiglumis* in this environment, it should be no surprise to find *Eulalia aurea* responding positively to a more sympathetic grazing regime, provided that a source of plants or seed still exists. Unfortunately, Hosking’s list suggests that *Eulalia aurea* (and possibly other key species) has been eliminated from some remnant sites.

Thus, although the assemblage of species that characterises the Liverpool Plains grasslands may not have changed appreciably, the relative abundance of species appears to have changed greatly, with some species that were formerly abundant, in particular *Themeda avenacea*, *Eulalia aurea* and *Astrebla lappacea* now rare or uncommon. *Austrostipa aristiglumis* was, almost certainly, a component of the grasslands, having been collected on the Plains within 30 years of occupation (Bentham 1878), but it is doubtful that it was the dominant species.

Management and research implications

Given the lack of compelling historical evidence for an original *Austrostipa aristiglumis* dominated grassland community on the Liverpool Plains, management strategies for grassland remnants should be designed to allow species that more reasonably represent the original communities to develop. Landholder experience indicates that a rotational grazing strategy can be used to encourage species that originally may have been much more abundant and are, in fact, more agriculturally desirable than *Austrostipa aristiglumis*.

Further research is required to assist in understanding and managing these grasslands. In particular, the current distribution and population trends of grassland species and both species and community dynamics, especially habitat requirements and response of key species to grazing regimes, need research. Furthermore, there is little or no information on environmental impacts on grassland composition, especially the two parameters mentioned in the historical literature – latitude and soil wetness. There is also little information on biodiversity and soil and grassland health. Martin (2003) proposed that small ground-foraging mammals played a key role in maintaining topsoil health and biodiversity, and that their impacts have implications for the management and restoration of remnant areas. Allan Cunningham in the 1820s (in Lee 1923) listed an array of non-grass species that presumably occupied the interstitial spaces, implying a dynamic and healthy grassland community where periodic disturbance opened the grass tussock canopy allowing non-matrix species to establish and grow. In fact, Nesbit (1831) noted that kangaroo rats were so abundant on the Plains and their diggings so numerous that it was potentially dangerous to gallop a horse across the Plains. The significance and role of disturbance and bioturbation in maintaining biodiversity and a dynamic and healthy grassland system, and the best means of achieving this in grassland remnants could also be profitable avenues for research.

Finally, attempts to establish and maintain trees in areas of naturally-treeless grasslands on the Liverpool Plains are inappropriate (except around homesteads) and will most likely encounter difficulties, given the hydro-edaphic factors that influence these communities.

Conclusions

NSW Lands Department portion plans and other historical documents can be used to identify the pre-settlement boundaries of naturally-treeless grasslands in areas such as the Liverpool Plains.

Principal driving processes of the grasslands appear to be fine-textured soils, topography and climate interacting to restrict water availability in the subsoil which severely restricts the development of woody vegetation.

The current dominance of *Austrostipa aristiglumis* is a consequence of European settlement, in particular heavy and continuous grazing by domestic stock and rabbits. Species that are now rare or uncommon, such as *Themeda avenacea* (Native Oatgrass), *Eulalia aurea* (Silky Browntop) and possibly *Astrebla lappacea* (Curly Mitchell grass) were originally more abundant and may have been dominant, with different suites of species occupying different habitats.

Management strategies for the naturally-treeless grasslands of the Liverpool Plains should aim to include *Austrostipa aristiglumis* as a component, rather than a dominant species, in order to develop and maintain a community more representative of the original community.

The ecology and dynamics of the Liverpool Plains grasslands require more research.

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Floristics, structure and site characteristics of *Melaleuca viridiflora* (Myrtaceae) dominated open woodlands of the wet tropics lowlands

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Abstract: Tropical lowland plant communities in north-eastern Queensland remain under pressure from continuing clearing, fragmentation, exotic species invasion, inappropriate fire regimes, and altered hydrological patterns. Comparatively little scientific research has been conducted on the highly diverse and ecologically significant range of remnant vegetation types. Additionally, most plant communities remain very poorly represented in the existing conservation reserve system. *Melaleuca viridiflora* Sol. ex Gaertn. open woodlands were selected for investigation based on their relatively simple structure, compared to other lowland communities, and the large extent to which they have been affected by past clearing patterns. A detailed analysis of community structure and composition was conducted at 24 sites throughout the wet-tropics coastal region between Townsville and Cooktown. Surprisingly, a high diversity of structural and floristic types was recorded, with a total of 127 species documented across the 24 sites. Classification analyses of species composition data produced seven or eight main groups of sites (dependent on the statistical technique used), essentially related to a gradient of latitude and rainfall. These floristic groups were not well explained by either species richness, past fire frequencies or soil types. Structural classification analyses based upon DBH data identified six or seven main groups, the singularly most striking of which were sites with annual fire histories. Ordinations based on both the DBH and species composition data produced groupings that supported those detected by the classification techniques. On closer examination of sites with similar fire histories, soil moisture and soil type were both found to have significant effects on community structure and composition. Many of the woodland types recorded are not adequately included (some not at all) in the existing conservation reserve system.

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Introduction

There is a relative dearth of baseline information on community ecology for most vegetation types of the tropical lowlands of north-eastern Queensland. This is despite wide acknowledgment that they continue to be the communities most impacted by development, and are some of the most poorly represented communities in conservation reserves (Braby 1992; Lavarack 1994; Stanton & Godwin 1989; Tait 1994; Webb 1966). An analysis of the lowland vegetation of the Cardwell region (Figure 1) showed that remnant vegetation was reduced by 6,900 ha (29%) in the fifty years between 1942 and 1992 (Skull 1998). *Melaleuca* woodlands and *Melaleuca* open woodlands were reduced by 30% and 53% respectively. This study sought to provide a detailed description of woodlands dominated by *Melaleuca viridiflora* (Broad-leafed Tea-tree or Paperbark), which are an integral component of the highly diverse tropical lowland habitat mosaic. The conservation priority for these woodlands ranges from high through to low depending upon their floristics, structure and position in the overall landscape (Kemp & Morgan 1999; Kemp et al. 1999).

General description

Classified structurally as open woodland (Walker & Hopkins 1990), *Melaleuca viridiflora* dominated woodlands have a relatively simple tree layer, with a complex understorey comprising many sedges, grasses and other herbs (Figure 2)(Skull 1995; Tracey 1982). Non-graminaceous herbs are particularly abundant in the wet, hot summer months. Gillison and Walker (1981) documented that these communities are usually two-layered with a ground layer (10–50 cm) of graminoids. Tracey (1982) noted that epiphytes were often conspicuous in the canopy trees and that weed invasion was likely following disturbance. Lavarack (1994) described a wide range of terrestrial and epiphytic orchids that collectively flower almost year round in this vegetation type.

The predominantly low moisture and nutrient status of the soils associated with these woodlands often means that they will only carry very mild fires as a result of low fuel loads (Gillison & Walker 1981). *Melaleuca viridiflora* is tolerant of a wide range of soil salinities, prefers seasonally saturated soils, and readily coppices (Tweddell 1982). These features, together with fire-resistant bark and the capacity to establish profusely from seed, ensure that this species is a highly effective coloniser and competitor (Gillison & Walker 1981).

Table 1. The seven themes of *Melaleuca viridiflora* woodlands identified by Stanton and Godwin (1989).

Theme number	Constant species	Commonly associated species	Features
13	*Melaleuca viridiflora*	*Lophostemon suaveolens, Grevillea pteridifolia*	Small areas in eucalypt forest, occupying run-on areas or patches of heavier soil.
14	*Melaleuca viridiflora*	Nil	Open forests developed on recent marine alluvium. Ground cover variable.
15	*Melaleuca viridiflora, Dillenia alata, Carallia brachiata*	*Buchanania arborescens, Atractocarpus sessilis*	Medium to tall forests on silty loam soils of poor internal drainage.
16	*Melaleuca viridiflora*	Nil	Monospecific low forest and woodland developed on a shallow mantle of sand over mangrove mud.
17	*Melaleuca viridiflora, Lophostemon suaveolens*	*Melaleuca quinquenervia, Acacia crassicarpa, Allocasuarina littoralis, Acacia mangium, Ischaenum australe*	Small low areas of seasonal swamp on sand plain.
18	*Melaleuca viridiflora*	*Melastoma malabathricum, Gahnia sieberiana, Banksia plagiocarpa*	Low forest, seasonal swamp.
19	*Melaleuca viridiflora, Lophostemon suaveolens, Grevillea pteridifolia*	*Corymbia clarksoniana, Xanthorrhoea johnsonii*	Grassy low woodlands of extensive plains.

Previous research

Other than the collection of baseline taxonomic and distribution information (Barlow 1989; Blake 1968), research within this vegetation type has focussed on a select number of plant species (particularly orchids) (Bartareau & Skull 1994; Jobson 1995; Lavarack 1994; Lawler 1993), even fewer animals (Anderson 1993; Braby 1992; Sommer 1990; van Dyck 1993), and rarely on entire communities. The only study to assess *Melaleuca viridiflora* specifically within the Wet Tropics Biogeographic Region (WTBR) (Thackway & Cresswell 1995), showed that this species reaches its highest densities on duplex soils, is capable of tolerating a wide range of salinities and is dominant where sites dried out markedly during the dry season (Tweddell 1982).

The floristics of the woodlands throughout the WTBR have been recorded as varying significantly in relation to controlling environmental factors (including soil type), constant canopy species and commonly associated species by Stanton & Godwin (1989), who recognized 119 "themes". Although no detailed data was collected or analysed, seven "themes" of *Melaleuca viridiflora* were described for the region as a basis for assessing the woodlands' conservation status at the time (Table 1). Others have described the structural variation that can occur in these woodlands, ranging from stunted, twisted trees (3–7 m) to more "pole" forest-like proportions in swampy areas (18–20 m) (Gillison & Walker 1981).

The physical structure of these woodlands has only been investigated in two other biogeographic regions of Australia (Top End Coastal and Cape York Peninsula). In the latter, Crowley & Garnett (1995) concluded that increases in the area of this vegetation type (at the expense of native grasslands) corresponded to changes in fire regimes as a result of the cessation of Aboriginal burning, a finding supported by Stanton (1992). In both regions, a lack of an understanding of regenerative processes following disturbance in Melaleuca communities is a management concern (Dr J. Russell-Smith, pers. comm.). Finlayson *et al.* (1993) have published details of the structure of a mixed *Melaleuca cajaputi* Powell/ *Melaleuca viridiflora* community on the Magela floodplain near Jabiru in the Northern Territory. The community exhibited a bell-shaped distribution curve across DBH size classes. Importantly, the site has remained unburnt for at least the past 20 years (Dr M. Finlayson, pers. comm.). General reductions in *Melaleuca* tree density across the same floodplain have also been documented and attributed to a combination of fire, water buffalo grazing and wind (Williams 1984).

Comparisons of the research results from other regions with those recorded in this study are, however, confounded by significant differences in annual fire regimes (including fire frequency, season and intensity), the scale of the habitats and the subsequent areas that are burnt on an annual basis, management practices (traditional vs. grazier vs. natural resource management) and environmental attributes such as rainfall, relative humidity and soil type.

Consequently, variation in structure and floristics of woodlands dominated by *Melaleuca viridiflora*, can reflect community differences in response to edaphic factors (soil type, climate) or successional responses to impacts of fire or grazing. This investigation therefore had the following objectives: (1) to conduct a detailed analysis of the structure

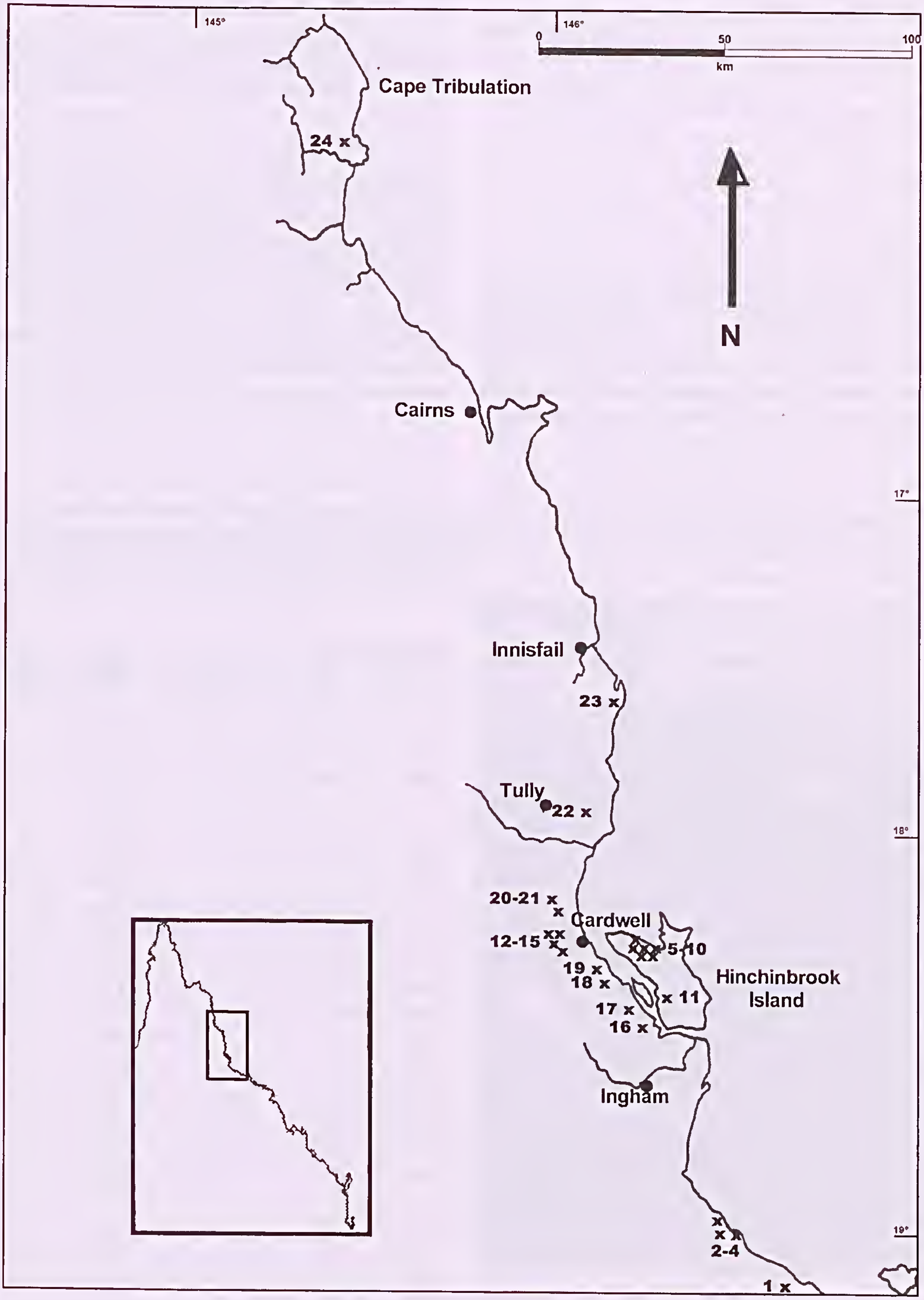

Fig. 1. Location of study sites (x) within the Wet Tropics Biogeographic Region.

of *Melaleuca viridiflora* woodlands within the WTBR, and (2) to assess the communities in terms of species composition, soil type, fire history and climate. A more detailed assessment of two of the most significant management issues facing these woodlands (fire and exotic species invasions) was also conducted (Skull 1998), and will be reported elsewhere.

Methods

Site selection

A combination of topographic maps, aerial photographs, previous vegetation surveys and consultation was used to select possible study sites. This study only investigated *Melaleuca viridiflora* communities that satisfied the following selection criteria: (1) the community was located within the coastal lowlands of the WTBR between Cooktown and Townsville; and (2) *Melaleuca viridiflora* comprised more than 70% of the trees in the uppermost stratum.

The general location of the study sites on the north-eastern Queensland coast, between Cooktown and Townsville (from 16°13’S to 19°06’S, a distance of some 470 km), is presented in Figure 1. Sites 1–4 were chosen to represent communities at the southern extremity of the WTBR. In the central section of the WTBR, sites were primarily selected within Hinchinbrook Island National Park (Hinchinbrook Island) (Sites 5–11) and the Wet Tropics World Heritage Area (Sites 16–21), as this is where a majority of these woodlands occur (excluding privately owned freehold land). Hinchinbrook Island National Park provided unique opportunities to study *Melaleuca viridiflora* communities in detail, as it is isolated from the mainland and therefore subject to far less disturbance in terms of habitat fragmentation, high fire frequencies, exotic plant invasion and feral animal disturbance.

Table 2. Summary of site data for *Melaleuea viridiflora* communities in the lowland wet tropics of north Queensland.
Notes: [1] = theme after Stanton & Godwin (1989), see Table 1; [2] = Soil type after Cannon *et al.* (1992) where C=Cudmore, Po= Porter, R=Rungoo, L=Lugger, T=Thorpe, M=Malbon, Pr=Prior; duplex (texture contrast) soils are indicated with an asterisk, all others are gradational); [3] = Fire frequency where 1 = 1 fire every year, 2 = 1 fire every 1–2 years, 3 = 1 every 5 years, 4 = 1 every 10 years and 5 = 1 every 20 years; [4] = number of site visits.

Site	Latitude	Longitude	Altitude (m)	Annual rainfall (mm)	Theme[1]	Soil type[2]	Fire frequency[3]	Species richness	Sampling effort[4]
1	19°06’00”	146°27’00”	10	1351	13	C	3	30	2
2	19°05’06”	146°18’00”	10	1402	13	Po*	4	18	2
3	19°05’06”	146°26’00”	30	1394	13	C	3	38	1
4	19°04’00”	146°26’00”	15	1410	13	C	3	33	1
5	18°16’06”	146°10’30”	10	2320	19	R*	4	49	13
6	18°14’48”	146°08’00	10	2300	19	R*	4	20	6
7	18°16’00”	146°09’30	10	2301	13	R*	4	14	3
8	18°16’30”	146°10’18”	20	2310	18	R*	4	10	6
9	18°16’30”	146°10’24”	20	2310	18	R*	4	15	6
10	18°16’30”	146°10’12”	15	2311	19	L	4	14	6
11	18°25’30”	146°13’30”	5	2205	16	T	4	16	2
12	18°15’06”	145°58’00”	10	2055	19	C	4	25	2
13	18°15’18”	145°58’12”	10	2038	19	C	4	11	2
14	18°15’12”	145°57’48”	10	2055	19	C	4	17	2
15	18°15’18”	145°57’36”	10	2038	19	C	4	18	2
16	18°30’00”	146°10’48”	5	2144	19	T	4	17	3
17	18°27’30”	146°09’00”	5	2134	19	L	1	15	2
18	18°20’12”	146°03’42”	10	2099	19	Po*	2	13	1
19	18°19’42”	146°02’36”	15	2076	19	M	3	27	8
20	18°11’30”	145°57’06”	10	2163	14	R*	3	16	1
21	18°10’42”	145°56’12”	10	2147	19	Pr	3	24	1
22	17°56’00”	146°01’30”	10	3262	19	R*	3	15	2
23	17°39’30”	146°39’30”	10	3213	17	T	5	15	1
24	16°13’00”	145°26’30”	15	3515	18	L	3	11	1
Mean ± SE	-	-	11.9 ± 1.1	2189 ± 119.3	-	-	-	20 ± 2	3 ±1

Central WTBR sites were also located on the mainland in the State Forest and adjoining private land west of Cardwell (Sites 12–15). Northern WTBR mainland sites (Sites 22, 23 and 24) were located in the Mission Beach, Cowley Beach and Cape Tribulation areas respectively (Figure 1).

Plot data collection

The location of each site was recorded with a handheld Garmin 100 GPS unit. Altitude was determined from topographic maps. Recent fire histories were assessed using past fire records (predominantly for sites within conservation reserves), or determined following discussions with local authorities and landholders.

Most of the woodland populations sampled were small and irregularly shaped. To ensure sample units were not located too close to ecotones, a transect was established through the middle of each population. Five 10 x 10 m plots (spaced 10 m apart) were established along the transect, with the starting point for the first plot of the transect selected at random. Plots were marked to enable re-examination following fire. Steel pegs were used to mark the corners of the plots, with aluminium tags (labelled with date and plot number) nailed into a reference tree close to a pre-determined corner of every plot, and above previous fire scars. All structural data were collected over a two month period in 1993.

To provide an estimate of species richness, all species within each community were recorded and a reference herbarium compiled. Species were collected at all sites throughout the range of tropical seasons (excepting remote sites), so as to obtain a complete reference collection. Species composition data were collected between August 1993 and November 1996. Plant names follow Henderson (2002).

All mature *Melaleuca viridiflora* trees taller than 1.5 m were counted and their diameter at breast height (DBH) recorded. Individual *Melaleuca viridiflora* plants (hereafter called woody sprouts) less than 1.5 m were counted. These would include some seedlings or young saplings, as well as vegetative resprouts, which are particularly produced in response to fire. Due to their predominance in the understorey of most sites, Grasstree (*Xanthorrhoea johnsonii* A.T.Lee) densities were also recorded.

A single soil profile to a depth of 1 m was examined (as close as possible to the site centre) at each site using a 7.5 cm diameter auger. A representative sample of each horizon sub-section was collected, systematically stored in a compartmentalised tray and subsequently classified according to Cannon et al. (1992).

To enable climate comparisons to be made with other regions where this community has been studied, mean monthly rainfall and relative humidity data for Townsville, Cardwell, Cooktown (all within the WTBR), Coen (Cape York Peninsula) and Jabiru (Top End Coastal) were obtained from the Bureau of Meteorology. The climate prediction system BIOCLIM (Busby 1991) was also used to predict climate parameters, including rainfall and temperature profiles for each of the study sites based on longitude, latitude and altitude.

Data analyses

The DBH (cm) data were sub-divided into nine DBH size classes. A cluster analysis was conducted on the *Melaleuca viridiflora* DBH data matrix to determine sites with similar structures using a Bray-Curtis (Czekanowski) association measure followed by flexible unweighted, pair group arithmetic averaging (UPGMA). This technique is a hierarchical, agglomerative clustering process available in the PATN software package (Belbin 1995b; a). All analyses closely followed the recommended procedure outlined by Belbin (1991).

This classification technique was tested against the polythetic divisive approach of TWINSPAN (two-way indicator species analysis) originally developed by Hill (1979). The analysis of DBH data used six cut levels (set at 0, 5, 10, 20, 30 and 50) with the minimum group size for division and maximum number of divisions set at two and five respectively. This

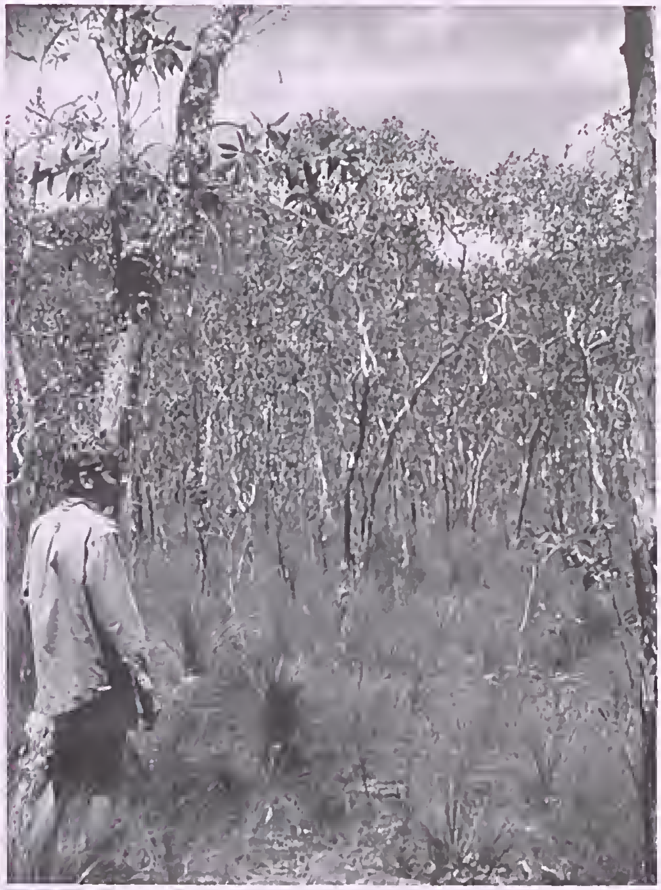

Fig. 2. A typical *Melaleuca viridiflora*-dominated open woodland community in Hinchinbrook Island National Park, with abundant grass trees (*Xanthorrhoea johnsonii*) in the understorey.

additional analysis was employed to determine which DBH groups (or species in the case of the species composition data matrix) were responsible for producing divisions/groupings of sites within the data matrix.

To test the discreteness of the groupings formulated by the cluster analysis, an ordination was performed using semi-strong hybrid multi-dimensional scaling (SSH). This ordination technique combines metric and non-metric multi-dimensional scaling (Faith 1991), and is also available within the PATN package. Three dimensions were chosen on the basis of the stress parameter (lack of fit), and for the third dimension 100 random starts were utilised to minimise the likelihood of local minima (Faith 1990). Site variables which appeared to be important with respect to site groupings (soil type, rainfall and fire history), were then superimposed on plots of the ordination vectors.

The species composition data were analysed according to the procedure outlined above for the DBH data matrix, except that two cut levels (0 & 1) and a maximum number of four divisions were used in the TWINSPAN analysis, and four dimensions were required to produce sufficiently low stress in the ordination. Species with a frequency of less than 5% for all study sites were not included in the analysis. As a result, 75 species were selected from the original list of 127.

Site groupings from selected multi-variate analyses were then tested for significant differences with respect to other parameters using one-way ANOVA. For the species composition data, species richness and predicted total annual rainfall were tested for significant differences between groupings of the Bray-Curtis classification. Groupings from both classifications of the DBH size class data were tested for significance based upon the raw DBH data for each site and predicted total annual rainfall. Tukey's HSD test was employed to determine which pairs of groups (if any) were significantly different at the 5% significance level. All uni-variate analyses were conducted using the SPSS software package (SPSS 1993).

Results

General characteristics of the sites

A total of 24 *Melaleuca viridiflora* populations were investigated during this project. Altitude ranged from five metres above sea level to 30 m, with the majority of sites 10–15 metres above sea level (Table 2). Four sites (1–4) had predicted annual rainfalls of less than 1500 mm, with most sites between 2000 and 2300 mm. Three sites were predicted to register more than 3000 mm annually (Sites 22–24).

Of the seven themes identified by Stanton and Godwin (1989), six were recorded during this survey (Table 2). Fifty-four percent of the sites were classified as Theme 19 with Theme 13 the next most abundant (21%). No Theme 15 (*Melaleuca viridiflora* associated with *Dillenia alata* and *Carallia brachiata*) was recorded. The seven soil types recorded during the survey were all derived from acid igneous rock (Cannon et al. 1992). Gradational soils were more predominant (63%) than duplex soils, although Cudmore (gradational) and Rungoo (duplex) series soils were equally abundant (30%).

Recent fire histories varied from annual fires at Site 17 to relatively low frequencies (Site 23), with most sites averaging a fire once every 5 to 10 years (Table 2). This moderate fire frequency was particularly common for sites on Hinchinbrook Island.

Community structure varied markedly for every parameter recorded (Table 3). Average DBH was lowest at Site 20, low for two other groups of sites (7–9 and 21–23) and high at Sites 17 and 18. The number of *Melaleuca viridiflora* individuals per 500 m^2 in the >1.5 m size class varied from 32 at Site 4 to 255 at Site 23. Understorey parameters (the number of *Melaleuca viridiflora* sprouts <1.5 m and Grasstrees) also had wide ranging densities. Canopy dominance of *Melaleuca viridiflora* was lowest at Site 11 (71%) and highest at Site 13 (100%). Species richness and sampling effort were not significantly correlated (Pearson correlation coefficient = 0.40, P>0.05). The density of *Xanthorrhoea johnsonii* in the understorey also varied greatly across the sites examined. Whilst absent at some sites (Sites 3, 4, 13 14 and 24), this species reached very high densities at others (Sites 6 and 9).

Whilst there was a large variation between sites, most individuals had a DBH of less than 20 cm (most commonly less than 5 cm). Site 20 was unusual in that it only had individuals with a DBH less than 10 cm, and Sites 17 and 18 appear distinct with the majority of individuals in the larger size classes.

Community analyses of study sites

Species composition data matrix

The Bray-Curtis clustering technique produced seven groupings (P1–P7) (Figure 3a) and TWINSPAN eight (P8–P15) (Figure 3b). The two approaches generally produced similar groupings. The initial Bray-Curtis division produced two groups, the first of which (P7) separated the four sites at the southern extreme of the WTBR (Figure 3a). These sites had few understorey native herbaceous species and midstorey shrubs. Native grasses and introduced pasture species dominated the understorey, contributing to a high species richness at Sites 3 and 4. These four sites shared several species in common, including *Themeda triandra* (Kangaroo grass), *Dendrobium canaliculatum* (Tea-tree orchid), *Pandanus tectorius* and a species of wattle. Conversely, the absence of species present at many other sites, including *Casuarina equisetifolia* L. subsp. *incana*, *Dianella* spp. and several other herbaceous species, was also a noticeable feature of this first group. The TWINSPAN classification also distinguished these sites from all others based on the presence of the grass *Eriachne ciliata* (Figure 3b).

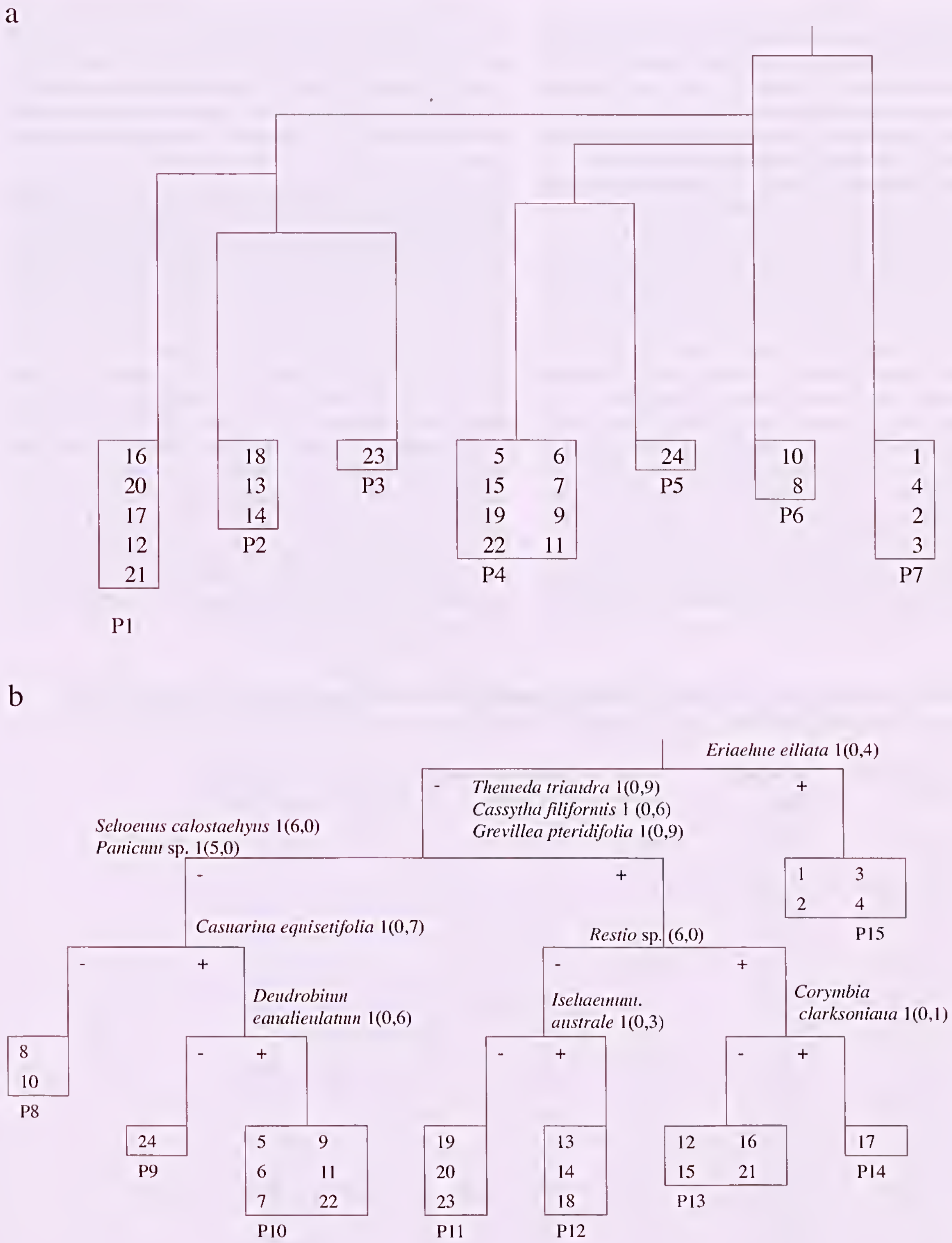
a
16
20
17
12
21
P1
18
13
14
P2
23
P3
5
15
19
22
6
7
9
11
P4
24
P5
10
8
P6
1
4
2
3
P7
b
Eriachne ciliata 1(0,4)
-
Themeda triandra 1(0,9)
Cassytha filiformis 1 (0,6)
Grevillea pteridifolia 1(0,9)
+
Schoenus calostachyus 1(6,0)
Panicum sp. 1(5,0)
-
+
1 3
2 4
P15
Casuarina equisetifolia 1(0,7)
Restio sp. (6,0)
-
+
Dendrobium canaliculatum 1(0,6)
-
+
Ischaemum. australe 1(0,3)
Corymbia clarksoniana 1(0,1)
8
10
P8
-
+
-
+
-
+
24
P9
5 9
6 11
7 22
P10
19
20
23
P11
13
14
18
P12
12 16
15 21
P13
17
P14

Fig. 3. Classifications of the species presence/absence data. (a) Classification of the species presence/absence data matrix utilising the Bray-Curtis association measure. End groups of sites are identified by codes (P1–P7). Groups of sites have been used to show the similarity of the SSH ordination results in Figure 4a. (b) Classification of the species presence/absence data matrix utilising TWINSPAN. Cut levels of 0 and 1. Indicator taxa, their abundance level and number of sites at which they occurred are given at each division. End groups of sites are identified by codes (P8–P14).

The second split in the Bray-Curtis division separated groups P4, P5 and P6 from groups P1, P2 and P3. P6 included Sites 8 and 10 (P6). These sites are at the two extremes of the soil moisture gradient (Skull 1998). It is therefore interesting that despite significant differences in terms of soil moisture, the sites are grouped according to species composition. Similarly, the TWINSPAN classification grouped these sites (P8-after three divisions) based upon the absence of the sedge *Schoenus calostachyus*, a species of Panic grass and the tree *Casuarina equisetifolia* subsp. *incana* (Figure 3b).

The next Bray-Curtis division produced a further two groups (Figure 3a). The first of these (P5) contained only one site, the most northern site investigated during this project (Site 24). This site had an understorey almost completely dominated by the giant sedge *Gahnia sieberiana* and *Melastoma malabathricum* subsp. *malabathricum*. Apart from other canopy trees (the most unusual being *Dillenia alata* which was only recorded from one other site, on Hinchinbrook Island (Site 11)), few other species were recorded. The second group (P4) contained eight sites, including all the remaining sites located on Hinchinbrook Island (Sites 5, 6, 7 and 9). Three mainland sites were also included in this group, two from the Cardwell region and the only one investigated in the Mission Beach region. The TWINSPAN classification also placed Site 24 on its own (P9), separated from six other sites at the fourth division based on the absence of the Tea-tree orchid *Dendrobium canaliculatum*, whose range does not extend that far north. The six sites that comprise P10 were all contained within a similar grouping produced by the Bray-Curtis approach (P4). Apart from Site 22 (located at Mission Beach), all sites were located on Hinchinbrook Island.

The final division of the Bray-Curtis classification produced three groupings (P1–P3), with P1 relatively similar to P2. The P1 group contained the majority of mainland sites in the Cardwell region, with the remainder in P2. The P3 group contained a single site (Site 23) which was the only one situated on an old sand dune system. Furthermore, this site was located near Cowley Beach, nearly 100 km to the north of Cardwell. Although this site contained no unique species, it had several (including *Melaleuca nervosa*) that were only documented at one other site. The TWINSPAN analysis produced a group identical to P2 (P12) at the fourth division based upon the presence of the grass *Ischaemum australe*. The P11 group matched none of those from the Bray-Curtis classification, whilst P13 contained three of the five members of the P1 group. Site 17 stood alone in the TWINSPAN classification based on the presence of *Corymbia clarksoniana*, which separated it from those sites in group P13 (Sites 12, 15, 16 and 21).

Table 3. Summary of structural data for *Melaleuca viridiflora* communities in the lowland wet tropics of north Queensland.
Notes: Standard errors are given in parentheses where appropriate; ^{1} = number of individuals in 500 m^2.

Site	Mean DBH (cm)	Mean height (m)	*Melaleuca viridiflora*			*Xanthorrhoea johnsonii*^{1}
			> 1.5 m^1	< 1.5 m^1	% of canopy	
1	8.6 (0.7)	9.2 (0.5)	54	341	74	107
2	13.1 (0.6)	13.3 (0.4)	46	89	98	14
3	10.8 (1.2)	10.0 (0.4)	85	45	97	0
4	13.7 (0.7)	12.5 (0.6)	32	330	86	0
5	19.3 (1.3)	5.9 (0.3)	128	158	99	504
6	19.2 (1.3)	4.9 (0.2)	107	84	98	705
7	5.0 (0.3)	4.0 (0.2)	88	79	72	540
8	4.3 (0.3)	3.3 (0.2)	53	154	95	175
9	5.9 (0.3)	4.2 (0.2)	142	154	96	725
10	13.2 (0.6)	9.5 (0.6)	55	94	74	30
11	7.6 (0.5)	6.2 (0.3)	114	44	71	139
12	10.4 (1.0)	7.3 (0.5)	43	75	77	242
13	11.5 (0.8)	10.3 (0.2)	62	50	100	0
14	9.8 (0.7)	6.7 (0.5)	83	123	73	0
15	9.5 (0.4)	6.4 (0.2)	74	53	89	130
16	21.2 (1.6)	5.6 (0.4)	80	275	99	466
17	34.7 (1.9)	11.2 (0.4)	48	360	96	368
18	32.4 (1.8)	10.4 (0.4)	57	65	99	307
19	9.6 (0.6)	7.6 (0.5)	51	276	78	397
20	3.1 (0.1)	2.7 (0.1)	215	900	75	333
21	5.4 (0.4)	5.8 (0.3)	182	298	75	390
22	5.1 (0.3)	4.6 (0.2)	149	3	73	97
23	5.2 (0.2)	2.7 (0.7)	255	149	84	6
24	12.7 (0.8)	9.6 (0.4)	87	0	82	0
Mean	**10.4 (0.2)**	**6.0 (0.1)**	**95 (12)**	**175 (39)**	**86 (2)**	**237 (47)**

The groupings defined by the Bray-Curtis classification were re-iterated by a plot of the first and second vectors from the ordination of the composition data (Figure 4a). Some overlap occurred between the P1 and P4 groupings of the classification, particularly Sites 16 and 19. These sites are both on the mainland and, although on different soil types, experience relatively infrequent fires. Soil types (especially gradational and duplex soils when combined) and fire history did not produce distinct patterns when overlaid on the ordination (Figure 4b and 4c respectively). Rungoo soils tended to clump together, with Cudmore soils predominantly falling to the left of the origin for Vector 1. Sites with fire histories of 1in 5 or 1 in 10 years formed a large group. Interestingly, although Sites 23 and 17 are very close together in the ordination space, they actually have the most different recent fire histories. Rainfall data overlaid on the species composition ordination produced some more definitive groupings (Figure 4d). High rainfall sites (Sites 22, 23 & 24) were arranged in a diagonal, linear fashion. Nearly all sites with either moderate or moderate-high rainfall fell below this diagonal and low rainfall sites above it. The exceptions to this were two sites with moderate-high rainfall (Sites 8 and 10), which formed a separate group above the linear diagonal.

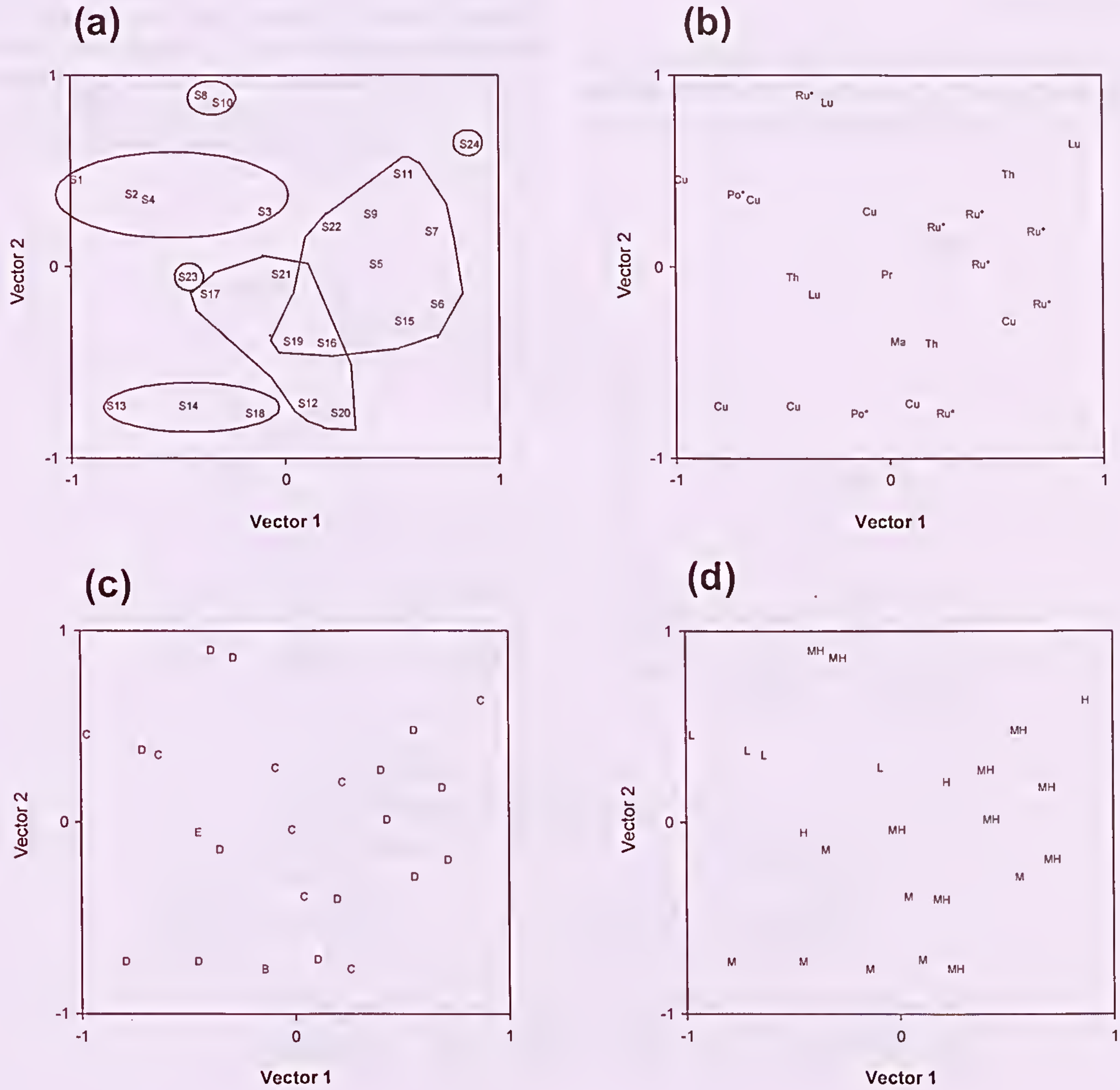

Fig. 4. Ordination of presence/absence data by SSH, Vector 2 vs. Vector 1 (S = site). (a) Sites overlain by groupings produced in the Bray Curtis classification of species presence/absence data, Figure 3a). (b) Sites with soil types superimposed (C=Cudmore, Po=Porter, R=Rungoo, L=Lugger, T=Thorpe, M=Malbon & Pr=Prior). (c) Sites with fire frequency imposed (A=1 fire every year, B=1 every 1–2 years, C=1 every 5 years, D=1 every 10 years and E=1 every 20 years). (d) Sites with rainfall superimposed (L=low: 1300–1700 mm, M=moderate: 1701–2100 mm, MH=moderate-high: 2101–2300 and H=high: > 2300).

As the two classification procedures and the subsequent SSH ordination results were generally very similar, only the Bray-Curtis results of the remaining community parameters are considered further here. Species richness did not differ significantly among the classification groups (*P*=0.19, *F*=1.65, d.f.=6), but predicted total annual rainfall based on latitude, longitude and altitude did (*P*<0.001, *F*=15.39, d.f.=6). The four southern WTBR sites (Group P7) had a significantly lower rainfall than all other groups (*P*<0.05). Group P3 (Site 23 near Cowley Beach, Innisfail) had a significantly higher rainfall than the majority of mainland sites in the Cardwell region (P2 and P1), and Site 24 (closest to Cooktown) had a statistically higher rainfall than all other sites except Site 23.

Structural data matrix

The Bray-Curtis classification of DBH data produced six species groups (Figure 5a) whilst the TWINSPAN analysis produced seven (Figure 5b). In both cases the first group to separate was that containing Sites 17 and 18 (D6 and D13). These sites had the highest recent fire frequencies and lacked any individuals with a DBH less than 2 cm (and taller than 1.5 m), had one each in the 2–5 cm DBH category and frequencies less than 10 for all other categories except 26–30 cm DBH and 31–35 cm DBH. There were large numbers of sprouts (<1.5 m) present (Table 3). The woodland structure is therefore simple, characterised by varying densities of sprouts and high mean DBHs.

The first division of the Bray-Curtis classification also separated eight other sites which split into two groups of five and three sites respectively (D4 and D5). Group D4 contained four of the six Hinchinbrook Island sites, which had very similar soil types, annual rainfall totals and fire histories (Table 2). Group D5 contained two sites near Edmund Kennedy National Park and the site at Cowley Beach near Innisfail (Site 23). Despite being situated on a range of soil types, all three sites had low mean DBHs (Table 3). The TWINSPAN classification also separated seven of these sites (second division) based upon a lack of individuals

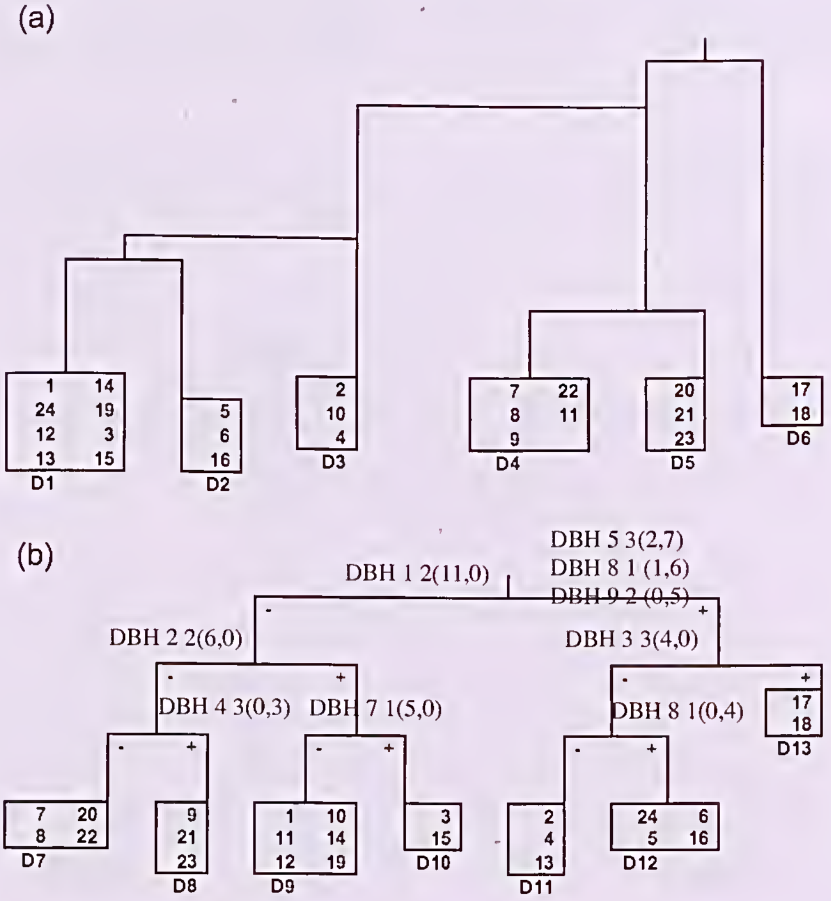

Fig. 5. Classifications of the DBH size class data matrix. (a) Classification of the *Melaleuca viridiflora* DBH size class data matrix utilising the Bray-Curtis association measure. End groups of sites are identified by codes (D1–D6). Groups of sites have been used to show the similarity of the SSH ordination results in Figure 6a. (b) Classification of the *Melaleuca viridiflora* DBH size class data matrix utilising TWINSPAN. Cut levels of 0, 5, 10, 20, 30 and 50. Indicator groups, their frequency and the number of sites at which they occurred are given at each division. End groups of sites are identified by codes (D7–D13).

in the 2–5 cm DBH category. The group was then further divided depending on the presence or absence of individuals in the 11–15 cm DBH category. These final two groups (D7 and D8) were very similar to those of the Bray-Curtis classification (D4 and D5).

The second division of the Bray-Curtis classification separated Sites 2, 4 and 10 (D3, Figure 5a) from the remainder. Two of these sites are in the southern section of the WTBR (Sites 2 and 4), with the third (Site 10) located on Hinchinbrook Island at the end of a soil moisture gradient (high moisture) (Skull 1998). TWINSPAN produced a similar grouping (but here Site 13 replaces 10) based on the absence of DBHs between 31–35 cm at the third division (D11, Figure 5b). The positive side of this division (D12) forms a grouping nearly identical to one of those from the final division of the Bray-Curtis classification (D2). Sites 5, 6 and 16 are identical themes identified by Stanton and Godwin (1989). Furthermore, they have identical fire histories and very similar mean DBHs and soil types (Tables 2 & 3).

The remaining eight sites from the Bray-Curtis classification (D1) are a similar group to those produced at the third division of TWINSPAN based upon the presence or absence of DBHs between 26–30 cm (D9 and D10). Group D1 contains a diverse group of sites from either end of the WTBR, which belong to different themes and with very different soil types and fire histories (Table 2).

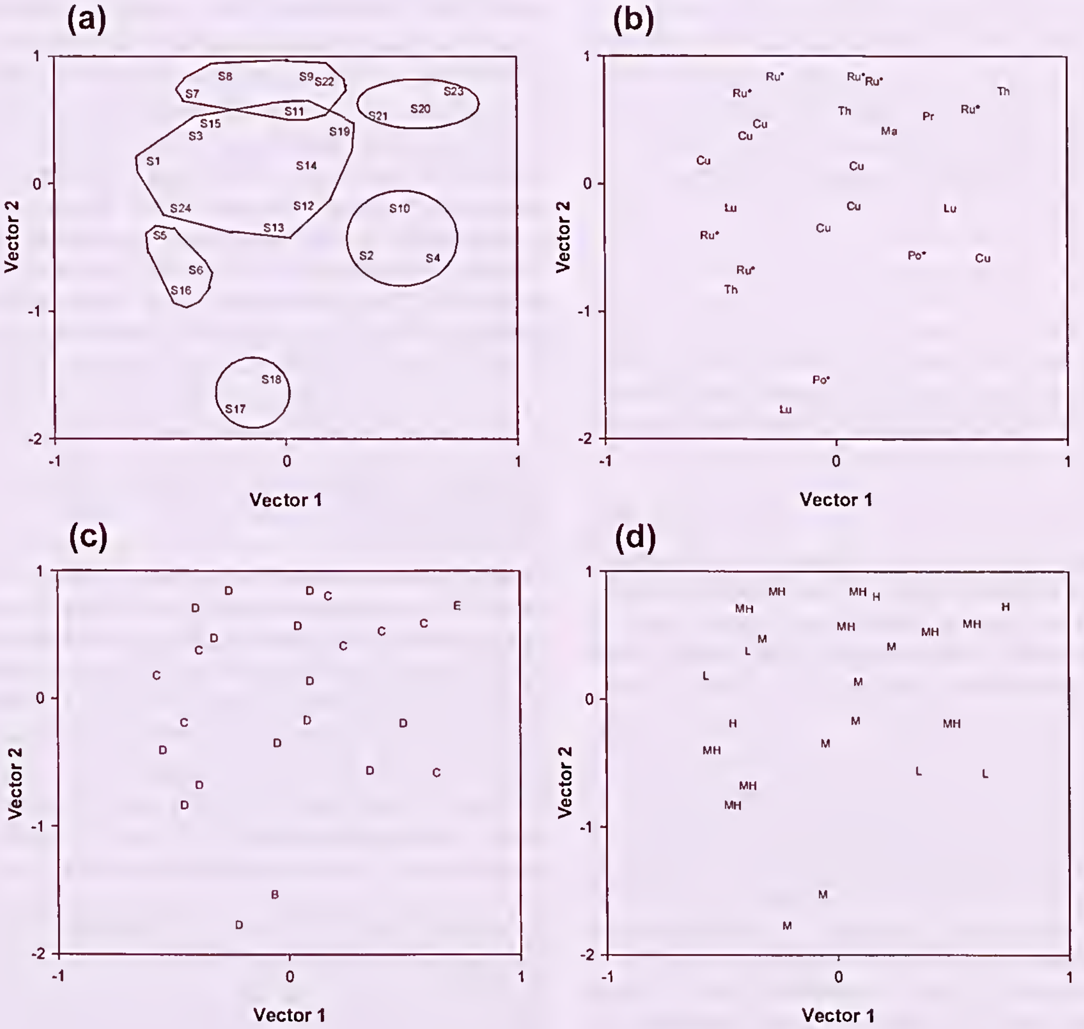

Fig. 6. Ordination of the *Melaleuca viridiflora* DBH size class data by SSH, Vector 2 vs. Vector 1 (S = site). (a) Sites overlain by groupings produced in the Bray Curtis classification of DBH size class data, Figure 5a). (b) Sites with soil types superimposed (C=Cudmore, Po=Porter, R=Rungoo, L=Lugger, T=Thorpe, M=Malbon & Pr=Prior). (c) Sites with fire frequency imposed (A=1 fire every year, B=1 every 1–2 years, C=1 every 5 years, D=1 every 10 years and E=1 every 20 years). (d) Sites with rainfall superimposed (L=low: 1300–1700 mm, M=moderate: 1701–2100 mm, MH=moderate–high: 2101–2300 and H=high: > 2300).

The SSH ordination produced groups identical to those of the Bray-Curtis classification (Figure 6a). Cudmore and Rungoo soil types were grouped together, with less pattern evident for other soil types (Figure 6b). Fire histories were well separated when overlaid on the ordination vectors (Figure 6c). Sites experiencing recent fire frequencies of either 1 in 5 or 1 in 10 years were grouped together, with those having lower or higher frequencies positioned on either side of the ordination space. Discernible patterns were less evident when the total annual rainfall data were superimposed on the ordination space (Figure 6d). Although some grouping of moderate and moderate-high rainfall sites occurred, sites with either low or high rainfall did not group particularly well.

The results of the one-way ANOVA on the site DBH data statistically confirmed the groupings formed in the Bray-Curtis classification ($P<0.001$, $F=415.49$, d.f.=5). Group D6 had a significantly higher mean DBH to all other groups, as did Groups D2 and D3 compared to Group D1 ($P\leq0.05$). No significant difference was recorded between Groups D4 and D5, which are located adjacent to each other in the classification dendrogram (Figure 5a). Rainfall did not vary significantly between the site groupings ($P=0.40$, $F=1.09$, d.f=5).

Discussion

The sites examined during this investigation varied considerably across the range of parameters recorded. Sites considered relatively adjacent at the landscape scale sometimes exhibited marked differences in either species composition, species richness, community structure, soil type or fire history. Sites essentially formed a continuum between the two extremes of this vegetation type described by Gillison and Walker (1981). Their "stunted, twisted woodland (3–7 m)" was recorded at several sites (Sites 7–9 and 20–23), and their "pole" forest-like community (18–20 m) at Site 10. Despite this variation in community structure, general trends in the data emerged.

Plant species have long been known to form distribution patterns with respect to environmental gradients such as rainfall (Kershaw & Looney 1985). This was re-iterated in this study, with species composition of the woodlands providing a basis for classifying the study sites into five major groups. Two sites (23 and 24) with high rainfall in the more northern section of the WTBR stood alone (Figure 3a), with the sites having the lowest predicted annual rainfall (1 to 4) separated from the majority in the central section of the WTBR. The Hinchinbrook Island sites tended to separate from the mainland sites in both the classification and ordination analyses (although this and other recorded similarities between the classifications and ordinations may, to some degree, reflect the sampling scale, the use of presence/absence data and the concentration of DBH data into too few size classes). Following the separation of southern WTBR sites, the next primary split in the species classification analysis was, interestingly, based upon the presence of *Grevillea pteridifolia*, (and *Cassytha filiformis* and *Themeda triandra*), and subsequently based upon *Casuarina equisetifolia* subsp. *incana*. Tracey (1982) noted that both these species were indicative of disturbance in *Melaleuca viridiflora* communities. The *Casuarina* formed small but often quite dense thickets in these woodland communities, sometimes resulting in the localised exclusion of the Tea-tree. The *Grevillea* was more dominant at mainland sites, particularly near roads and where fires were relatively recent or frequent, but probably also related to lack of salinity and lack of all-year round waterlogging in soil (RO Makinson pers. comm.).

Although some patterns emerged when other site data were superimposed on the species composition ordination (soil type and fire history), these appeared to be much less distinctive. Difficulties in classifying soil types from samples collected by auger are well documented, with this method one of the least preferred for site classification (McDonald et al. 1990). The isolation of many sites, coupled with the number investigated, precluded any more detailed methodologies (e.g. relatively large open pits) being employed. Furthermore, many of the characteristics used to distinguish the main soil types (gradational and duplex) are readily observed in auger samples. Accurately assessing the extent of these characteristics is, however, difficult. In addition, lowland soils are widely acknowledged as being highly variable over short distances (Mr M. Cannon, pers. comm.). This could result in a woodland community actually being situated on several variations of a given soil series, making classification of a site difficult at best. Future work could target this problem and ensure the soil types identified here are accurate.

Similarly, the accuracy of the fire history data is likely to be variable. Whilst some histories were obtained from records kept on conservation reserves, many were formulated solely from discussion with land-owners. The lack of accurately recorded fire histories has frustrated other researchers in tropical ecosystems (Bowman 1992), and remains a major obstacle to improved fire management of conservation reserves. An attempt at fire dating using *X. johnsonii* stem tissue scars proved unsuccessful and, furthermore, this species was not recorded at all sites. The use of *Xanthorrhoea* fire scars has been shown to be a useful method for determining past fire histories by researchers in temperate systems (Bulow-Olsen et al. 1982; Gill & Ingwersen 1976). Fire history and soil type may interact with climate, making detection of pattern with respect to single variables difficult. Furthermore, it is important that classification schemes are based not only on the species present, but also on measures of abundance, distribution, size and vigour (Kershaw & Looney 1985).

The most striking result from the multi-variate analyses of the structural data was the separation of those sites with annual fire regimes (Sites 17 and 18). These sites had a collective total of only 10 *Melaleuca viridiflora* individuals in the four smaller DBH size classes (≤15 cm). Modal frequencies occur in the largest DBH size class (>36 cm), with moderate numbers of sprouts in the understorey. In comparison, sites with lower fire frequencies typically have more bell-shaped distributions across the size classes (e.g. Sites 1, 3, 6 and to a lesser extent Sites 13 and 16). The only other published data on the structure of similar *Melaleuca* communities also recorded a bell-shaped curve and, importantly, the community had remained unburnt for at least 20 years (Finlayson et al. 1993). The structure of frequently burnt communities suggests that recruitment of a midstorey, and, in the long-term, canopy is being prevented. This has drastic implications for the longevity of these communities and represents a large management challenge as the sites are both located outside the existing conservation reserve system.

These sites provide an ideal opportunity for future assessment, particularly if fire management practices can be altered. This would allow repeated monitoring to determine if a cohort of individuals can survive to the midstorey and beyond. Alternatively, if management practices are not adjusted, what is the long-term fate of these sites? Perhaps a change to grassland. This would, in effect, be the converse of research findings on Cape York where infrequent firing of grassland communities has resulted in *Melaleuca viridiflora* invasion and a more woodland-like community developing (Crowley & Garnett 1995). Alternatively, these woodlands may become dominated by other species that are known to become more prevalent following disturbances including fire (e.g. *Grevillea pteridifolia*, Tracey (1982)).

The seven themes of *Melaleuca viridiflora* woodlands identified by Stanton and Godwin (1989), although taking into account soil type and a degree of floristic information, make no allowance for a detailed assessment of community structure. This is also absent from other floristic (e.g. Specht *et al.* (1995)) or semi-quantitative classifications (e.g. Kemp *et al.* (1999)) of plant community conservation status relevant to the WTBR. Specht *et al.* (1995) consider that conservation of these open woodlands in Australian is adequate (the highest rating), whilst locally they are considered to have a conservation priority ranging from high (several themes) to medium (most themes) to low (one theme only) (Kemp & Morgan 1999; Kemp et al. 1999).

This research highlights the extensive variation in species composition and community structure exhibited by these communities, many of which have disappeared from localised areas of the landscape in the past 50 years (Skull 1998). Although some sites are in fact situated within the existing conservation system (especially within Hinchinbrook Island), many remain unprotected examples of either different species assemblages or structural types, some of which may represent different successional stages of the same community type or theme. Wilson (1996) has highlighted the need that some faunal groups have for structural diversity within habitat types, a parameter he considered essential for biodiversity conservation. As recently as 1989, Themes 16 and 19 (accounting for more than half of the study sites investigated) remained poorly protected in the conservation reserve system (Stanton & Godwin 1989). This situation persists today. Until a more comprehensive range of the variation documented here becomes protected within conservation reserves and managed holistically across the landscape, the conservation status of these woodlands will remain well below ideal.

Past research efforts coupled with those of this study have recorded more than 300 plant and animal species from *Melaleuca viridiflora* open woodlands, with a further 12 orders of leaf and soil macro-invertebrates. This high biodiversity further underlines both the importance of these woodlands as an integral component of the WTBR lowland habitat mosaic, and the urgent need to improve their current conservation status.

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Appendix 1. Species, with a frequency of occurrence >5%, recorded from each study site. *Introduced species.

	Site																								
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**%**
Acacia aulacocarpa	+		+		+																				12.5
A. cincinnata					+							+			+						+				16.7
A. crassicarpa	+		+	+	+							+		+	+						+		+		37.5
A. flavescens	+									+															8.3
A. mangium					+									+	+										12.5
Acacia sp.	+	+	+	+		+								+	+	+					+			+	41.7
Alloteropsis semialata	+	+		+								+				+			+		+				29.2
Aristida latifolia			+		+																				8.3
Alphitonia excelsa									+		+	+	+												16.7
Alysicarpus sp.	+	+	+																						12.5
Bothriochloa sp.	+		+	+																					12.5
Byblis liniflora			+	+	+			+																	16.7
Casuarina equisetifolia subsp. *incana*					+	+	+		+		+	+	+	+	+	+						+	+	+	54.2
Cassia sp.	+			+																					8.3
Cassytha filiformis			+									+				+	+			+	+		+		29.2
Centranthera cochinchinensis		+	+										+												12.5
Chrysopogon fallax												+									+				8.3
Corymbia clarksoniana	+	+	+	+	+									+			+								29.2
C. intermedia												+									+				8.3
C. pellita	+		+																		+				12.5
Crinum pedunculatum			+												+										8.3
Crotalaria montana	+			+																					8.3
Cyperus sp.			+	+	+			+	+	+	+		+	+				+	+			+	+		54.2
Dendrobium canaliculatum	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+		+		+	+			75.0
Dianella caerulea					+	+					+				+	+		+		+	+	+			37.5
D. revoluta					+							+			+				+						16.7
Dillenia alata											+													+	8.3
Dischidia nummularia			+		+							+			+	+	+		+			+		+	37.5
Drosera spathulata					+	+	+		+			+			+				+	+		+			37.5
Ectrosia sp.			+																+						8.3
Eriachne ciliata	+	+	+	+																					16.7
Euphorbia sp.	+			+																					8.3
Fern sp.								+									+		+	+	+	+		+	29.2
Fimbristylis sp.											+	+									+				12.5
F. dichotoma			+	+	+	+				+									+		+				29.2
Goodenia paniculata			+		+	+	+											+	+						25.0
Gonocarpus acanthocarpus					+		+	+	+	+							+					+			29.2
Grevillea pteridifolia		+	+									+	+	+	+	+	+	+	+	+	+				50.0

Habenaria sp.					+							+					+								12.5
Haemodorum coccineum					+	+								+	+				+	+					25.0
Hibbertia melhanioides					+	+																			8.3
Ischaemum australe				+	+	+							+	+				+							25.0
Jacksonia thesioides						+														+					8.3
*Lantana camara**			+																		+				8.3
Lomandra sp.			+		+											+				+					16.7
Lophostemon suaveolens	+	+	+	+	+	+	+		+	+	+			+	+				+	+	+	+	+	+	75.0
Loranthaceae sp.			+													+				+			+		16.7
Melaleuca nervosa	+																						+		8.3
Melaleuca viridiflora	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	100
Melastoma malabathricum					+	+		+	+	+		+	+	+	+	+			+	+	+	+		+	62.5
Myrmecodia beccarii			+	+	+									+	+	+			+			+			33.3
Orchidaceae sp.			+																					+	8.3
Pandanus tectorius	+	+	+	+	+					+					+						+	+			37.5
Panicum sp.					+	+	+		+		+								+						25.0
Paspalidium sp.					+						+														8.3
Persoonia falcata					+	+		+	+						+	+									25.0
Petalostigma banksii		+		+																					8.3
Phyllanthus virgatus	+																	+							8.3
Pimelia sp.	+				+																				8.3
*Pinus caribaea**												+	+	+	+										16.7
Planchonia careya	+			+																					8.3
Poaceae sp.			+																				+		8.3
Restio sp.					+	+	+		+				+	+				+	+	+		+	+		45.8
Rhyncospora sp.			+	+						+											+				16.7
Ruellia sp.		+																	+			+	+		16.7
Schoenus calostachyus			+		+	+	+		+		+													+	29.2
Scleria tricuspidata			+	+	+					+		+													20.8
Spermacoce brachystema	+			+															+						12.5
Striga curviflora	+	+		+																					12.5
Stylidium sp.			+	+	+	+			+		+	+			+			+							37.5
Themeda triandra	+	+	+	+												+	+	+	+	+	+				41.7
Tricoryne anceps					+							+						+			+				16.7
Thysanotus banksii			+	+			+					+													16.7
Xanthorrhoea johnsonii	+	+			+	+	+		+	+	+	+			+	+	+	+	+	+	+	+	+		75.0
Xylomelum scottianum	+				+				+																12.5
Xyris sp.				+						+									+	+					16.7

Vegetation and floristic diversity in Gibraltar Range and part of Washpool National Parks, New South Wales

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Abstract: The vegetation of Gibraltar Range National Park and adjoining parts of eastern Washpool National Park, 65 km east of Glen Innes (29° 31'S 152° 18'E) on the eastern escarpment of New South Wales is described. In total 124, 20m x 50m full vascular plant floristic sites were recorded and information from an additional 53 sites was collated. Thirteen vegetation assemblages are defined based on flexible UPGMA analysis of cover-abundance scores of all vascular plant taxa. Many of the vegetation communities are typical of what is found along the north eastern escarpment of NSW. Three communities are considered to be rare and two vulnerable. A total of 878 vascular plant taxa from 138 families were recorded, of which only 21 (2%) were of introduced origin and 81 (9%) were found to be of conservation significance. Pattern diversity, species density, species accumulation and average geographic range size, along with general measures of richness and diversity, were analysed for all communities. Each of the communities described varied considerably in the diversity attributes measured. Communities with a high number of shrubs had greater constancy between sites compared to those that contained a high number of closed forest species. The community from rock outcrops had the largest average geographical range size.

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Introduction

The Washpool/Gibraltar Group of the Central Eastern Rainforest Reserves of Australia (CERRA) is a World Heritage-listed area that contains the largest expanse of coachwood warm temperate rainforest in the world (RACAC 1996; Adam 1994). It also includes one of the largest areas of un-logged sclerophyll forest in New South Wales, and significant sections of wild and scenic rivers supporting riparian rainforest. Two declared wilderness areas occur within the study area: Bindery-Mann and Washpool.

This paper presents part of the results of a comprehensive flora and vegetation survey of Gibraltar Range National Park and adjoining sections of eastern Washpool National Park. These areas lie approximately 65 km east of Glen Innes and 90 km west of Grafton (Fig. 1) (29°31'S 152°18'E). This investigation was commissioned by the Northern Tablelands Region of the NSW National Parks and Wildlife Service in order to provide baseline information to assist in determining appropriate land management strategies (Sheringham & Hunter 2002). In addition to the descriptions of vegetation communities we have also assessed changes in diversity attributes between the described assemblages. These diversity attributes can be used along with the baseline community information to provide further assess the conservation value and internal dynamics of the vegetation communities described.

European landuse history and reservation

Due to the rugged nature of the local terrain, the region was not accessed by graziers until around 1850. Gibraltar Range was initially used as a stock route linking the tablelands to the coast (Wright 1991). Tin and gold were discovered as early as 1852 leading to an influx of people to the area. Commercial logging followed, particularly in the Washpool and Cangai areas up until the 1980s (Adam 1987).

The Gwydir Highway, opened in 1960, runs through the middle of the study area and provides the main link between Grafton and Glen Innes. The building of this road was the catalyst for the establishment of Gibraltar Range as a reserve in 1963. The original dedication incorporated 14 000 ha for public recreation administered by the Department of Lands. In 1967 Gibraltar Range National Park was gazetted and taken under the management of the newly formed National Parks and Wildlife Service. Adjoining areas of State Forest have been added since that time, and presently Gibraltar Range National Park covers 25 406 ha.

Washpool National Park was gazetted in 1983 as a result of the enactment of legislation designed to resolve disputes over the logging of rainforest in New South Wales. All rainforests on public land in New South Wales were protected as a result of the *Forestry Revocation Act 1983*. Washpool National Park was established following the enactment of the *National Parks Reservation Act 1984*. Washpool National

Park is included on the World Heritage list (Gondwana Rainforests of Australia) and a significant proportion of the park is a declared wilderness area. Large areas of State Forest (Spirabo, Little Spirabo, Curramore, Moogem and Forest Land State Forests) were added to Washpool National Park in 1999 following the Comprehensive Regional Assessment of public forests in upper northeast New South Wales. Further strategic purchases of adjoining private lands consolidated the park During the 1990s Nymboida and Barool National Parks, which directly adjoin Gibraltar Range and Washpool National Parks, were also added to the reserve network.

Climate and weather

The climate of the study area is influenced by its location on the edge of the Great Escarpment. Annual rainfall increases with altitude along the eastern edge (1200–1300 mm) to the central plateau (>2000 mm) and decreases to the west (Bureau of Meteorology 1999). Mean annual temperatures range between 12°–13°C on the central plateau and 17°–18°C on the eastern escarpment. Mean maximum temperatures are in the mid thirties on the eastern escarpment edge and the high twenties on the plateau with a mean minimum temperature of 0°–5°C for the plateau and escarpment. The warmest months are November to March.

During the early part of the day, tablelands winds dominate; coastal winds move in during the mid to late afternoon. Late afternoon thunderstorms accompanied by lightning strikes, heavy rain and sometimes hail are a frequent event in summer. Widespread rain of reduced intensity but longer duration is typical of winter weather patterns.

Landform

Much of the study area is of undulating to steep topography dominated by extensive outcropping and subsurface granite sheets, boulder fields and nubbins. Three main watercourses drain the study area (Dandahra, Coombadjah & Grassy Creeks) frequently following joints and faults within the underlying granite and often forming waterfalls. The flatter terrain on the central plateau contains areas of impeded drainage forming large mires on Quaternary alluvium.

The Demon fault forms the western boundary of the study area. Here the granite plateau drops precipitously into the Cooraldooral Creek valley. This area forms a dividing line between the resistant Dandahra Granite and the weathered metasediments of the Coffs Harbour Association. Boulder and Boundary Creeks drain north and south respectively along this major fault line. The altitude within the study area ranges from 300 m on the lower reaches of Dandahra Creek to over 1170 metres at Waratah Trig and Summit Mountain.

Earlier botanical explorations

Although botanical exploration took place in the north east of New South Wales in the early 1900s, detailed exploration of the Gibraltar Range National Park did not take place until the early 1960s. At this time, botanist John Williams, of the University of New England at Armidale, made many plant collections in the Gibraltar Range and compiled an unpublished species list of the rainforest and granite species. Floyd (1990) undertook a detailed inventory of NSW rainforests using random irregular traverses. Many of these were undertaken in the current study area. Hunter (1991) placed belt transects within the reserve in an investigation into the demography of *Brachyloma* species. Some investigations into species biology and fire responses have recently occurred (Caddy & Gross 2006; Croft et al. 2006; Vaughton & Ramsey 2006; Virgona et al. 2006; Williams & Clarke 2006).

Though much botanical exploration has been done in the Gibraltar Range area, particularly within close proximity to the Gwydir Highway, few detailed systematic vegetation surveys have been undertaken. During comprehensive regional surveys in north-eastern New South Wales (NRAC 1995; NPWS 1994; NPWS 1999) over 30 systematic sites were placed in the Gibraltar Range National Park Hunter (1999) placed 34 systematic sites to describe the granite outcrop communities. Hunter & Clarke (1998) subsequently described nine floristic elements and 28 vegetation communities on the New England Batholith, two of which occur in the study area. Williams (1995) and Williams & Clarke (1997) surveyed the sedge heaths in Gibraltar Range National Park. More recently Hunter & Bell (2007) surveyed the sedge heaths (bogs) of the region, including those in the study area, and described these communities in detail along with aspects of species composition and richness relating to climatic and spatial factors.

Many adjoining areas have been systematically sampled for flora and vegetation and include the state forests of the Glen Innes Management Area (Binns 1992), the western extensions to Washpool National Park (Hunter 1998b; 2000b; 2005a), Nymboida National Park (Benwell 2000) and Mann River Nature Reserve (Hunter 2004b).

Methods

Vegetation survey and community classification

The survey was carried out in a stratified random manner in order to sample and replicate major environmental changes. The strata used were a combination of mapped geological, altitude and broad scale vegetation units (plateau complex, dry open forest, wet open forest, disturbed remnant and rainforest). The combination of these elements produced 24 strata; sites were allocated to these strata based on the number of hectares covered. Additional sites were placed in specialised communities that were not included in the *a priori* sampling strategy or to stratified classes that were not spatially replicated in the sampling design. 124 x 0.1 ha full vascular plant floristic sites were surveyed specifically for this investigation, together with information from an additional 53 sites; a database of 177 sites.

Good quality voucher material of species that needed confirmation of identification were lodged at the Coffs Harbour Herbarium (CFSHB). Nomenclature follows that of Harden (1993; 2000; 2002) except where more recent taxonomic changes have been made.

Analysis and data exploration were performed using options available in the PATN Analysis Package (Belbin 1995a & b). A scree plot analysis was performed to assess the most appropriate level of dissimilarity for community definition. For final presentation of results all species (including exotics) and their cover abundance scores were used. Analysis was performed using the Kulczynski association measure, which is recommended for ecological applications (Belbin 1995a & b) along with flexible Unweighted Pair Group arithmetic Averaging (UPGMA) and the default PATN settings.

Rock outcrops were not part of the stratification as these areas were deemed to have been sufficiently surveyed and described (Hunter & Clarke 1998). Evidence for the distinctiveness of outcrop assemblages from the surrounding matrix of the study area is given in Hunter (2002a).

Geographic range size

The mean geographic range size of the component flora has been calculated for each of the communities defined to assess their level of endemicity and uniqueness. This was achieved by creating a matrix of all species from each community scored according to their occurrence in each of the 97 'ecological regions' of Australia, as defined by Hnatiuk (1990). The richness of each within each 'ecological region'

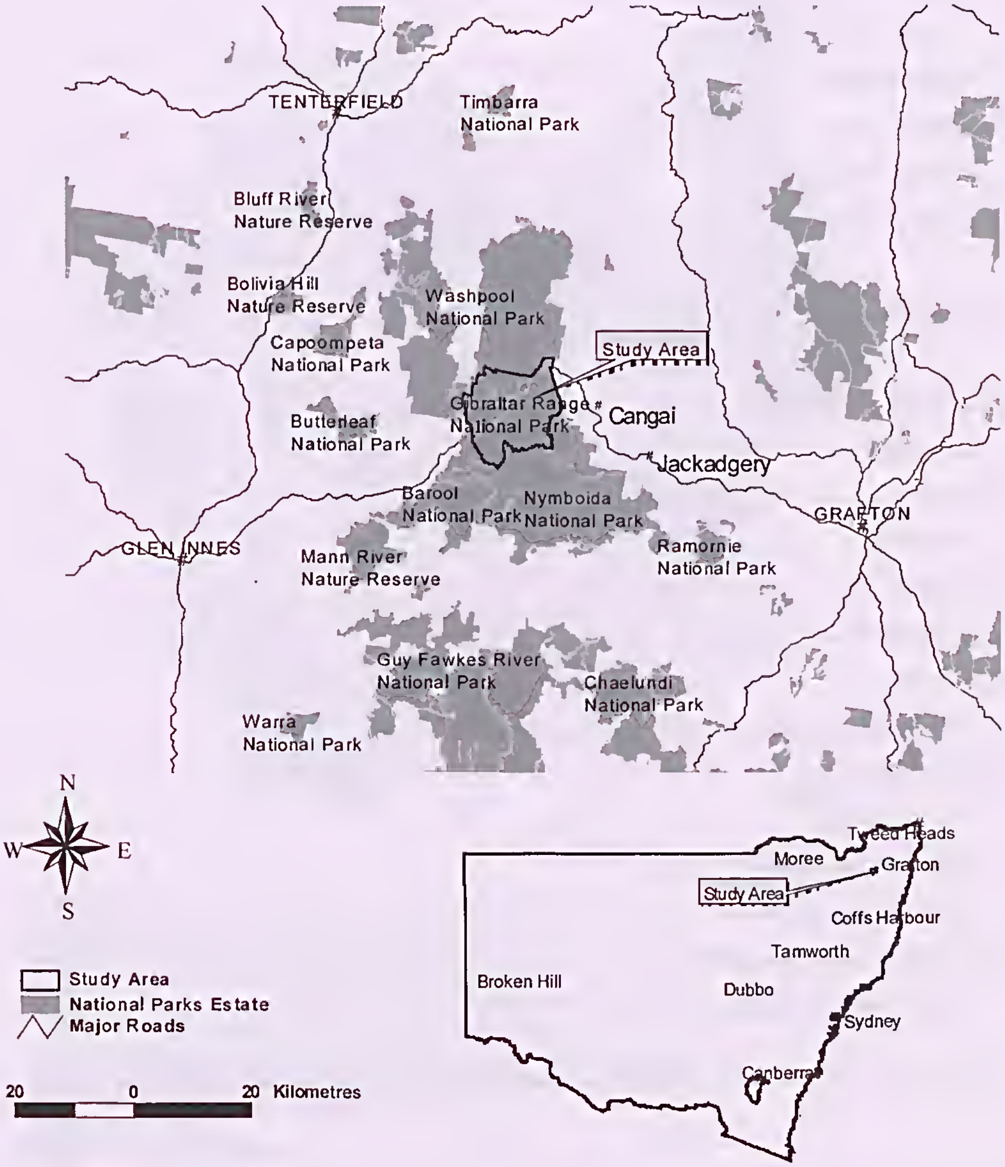

Fig. 1. Location of the study area.

was divided by the total species pool size of each community as captured in survey sites. These scores were then summed across all the 97 'ecological regions' in order to produce a score that represented the average occupancy of the flora of each community across all the 'ecological regions'. A higher score indicates that on average the flora of the community is more widespread, i.e. occupy more 'ecological regions' within Australia.

Species diversity patterns

Species diversity is derived from a combination of species richness, measured as the number of species per sample area (density) and the evenness of abundances. Aspects of richness are the most commonly studied, and differences between their values arise from geographical patterns of speciation, extinction and re-establishment ability (Hunter 2005d) and therefore are of importance in designing management plans for conservation.

Here species density is defined as the number of vascular plant species predicted to be found within 0.1 ha of sample area after 1000 randomised iterations of each community dataset with at least four samples using *EstimateS* (Colwell 1997). Modelling density in this fashion, within each defined community, is advantageous as it avoids spatial pseudo-replication in subsequent between community comparisons (Hurlbert 1984; Srivastava 1999; Gering & Crist 2002; Hunter 2005d).

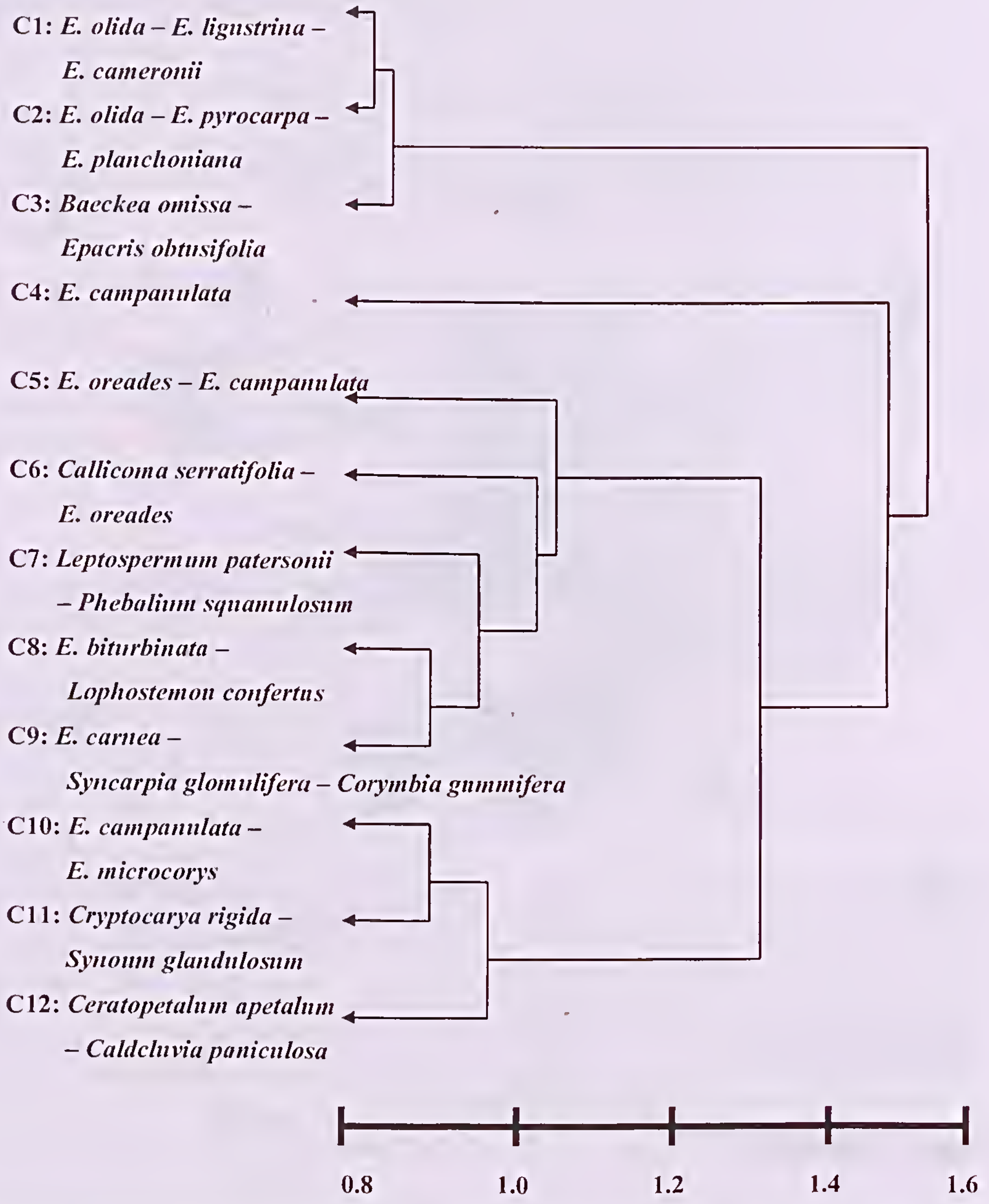
C1: *E. olida – E. ligustrina – E. cameronii*
C2: *E. olida – E. pyrocarpa – E. planchoniana*
C3: *Baeckea omissa – Epacris obtusifolia*
C4: *E. campanulata*
C5: *E. oreades – E. campanulata*
C6: *Callicoma serratifolia – E. oreades*
C7: *Leptospermum patersonii – Phebalium squamulosum*
C8: *E. biturbinata – Lophostemon confertus*
C9: *E. carnea – Syncarpia glomulifera – Corymbia gummifera*
C10: *E. campanulata – E. microcorys*
C11: *Cryptocarya rigida – Synoum glandulosum*
C12: *Ceratopetalum apetalum – Caldcluvia paniculosa*
0.8
1.0
1.2
1.4
1.6

Fig. 2. Summary dendrogram of sites surveyed during this investigation using Kulczynski association and flexible UPGMA fusion strategy. Communities are defined at a dissociation of 0.8.

It is of great importance that the method for determining pattern diversity (spatial turnover within a habitat or community) matches the aims of the study, as no single estimator can model all aspects of geographical species turnover (Heegaard 2004). Many issues arise from currently used methods for determining turnover particularly as many measures tend to ignore the magnitude of gains and losses between sample units, or describe compositional differences more than differences in species richness (Whittaker 1960, Koleff et al. 2003). Here the slope of a log-log plot of the discontinuous Coleman curve (species accumulation curves) which has been calculated after 1000 randomisations of each community dataset containing a minimum of four sample sites using *EstimateS* (Coleman 1981, Colwell 1997) is used as a surrogate for pattern diversity. This method was first described and used by Hunter (2005d). As each community has been delineated at the same dissimilarity they are of at least a minimal and similar floristic independence (Kulczynski dissimilarity of 0.8.).

Results

Floristics

A total of 878 vascular plant taxa were recorded from existing site data and subsequent sampling in the present study (Appendix 1). Only 21 (2%) taxa recorded were introduced/exotic. 552 taxa were recorded from the 124 new survey sites and a further 224 were recorded opportunistically. The remaining 97 taxa were recorded from previous surveys but not during this investigation. The recorded taxa represented 450 genera in 138 families. The families with the greatest

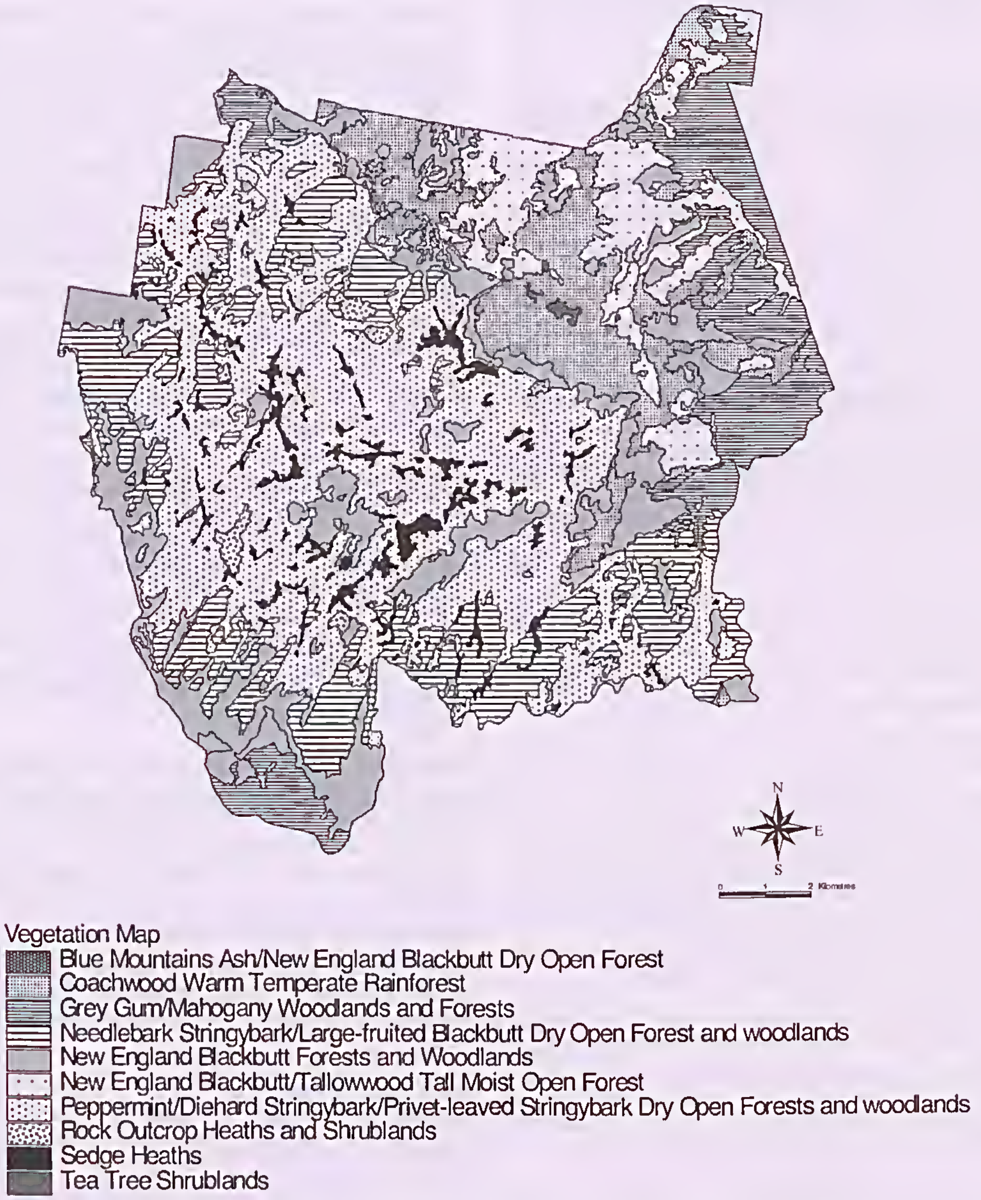
N
W
E
S
0
1
2 Kilometres
Vegetation Map
Blue Mountains Ash/New England Blackbutt Dry Open Forest
Coachwood Warm Temperate Rainforest
Grey Gum/Mahogany Woodlands and Forests
Needlebark Stringybark/Large-fruited Blackbutt Dry Open Forest and woodlands
New England Blackbutt Forests and Woodlands
New England Blackbutt/Tallowwood Tall Moist Open Forest
Peppermint/Diehard Stringybark/Privet-leaved Stringybark Dry Open Forests and woodlands
Rock Outcrop Heaths and Shrublands
Sedge Heaths
Tea Tree Shrublands

Fig. 3. Vegetation map of Gibraltar Range National Park and the southern parts of Washpool National Park.

number of taxa recorded were Fabaceae (85 taxa), Myrtaceae (74), Orchidaceae (66), Asteraceae (42), Poaceae (44), Cyperaceae (33), Proteaceae (27), Rutaceae (25), Ericaceae (21), Euphorbiaceae (17) and Lauraceae (16). The richest genera were *Eucalyptus* (30), *Acacia* (24), *Leptospermum* (12), *Hibbertia* (11), *Solanum* (10), *Pterostylis* (8), *Callistemon* (8), *Leucopogon* (8), *Lepidosperma* (7), and *Cryptocarya* (7).

Vegetation

12 plant communities are described (Figure 2) with species listed in order of decreasing summed cover-abundance score in each stratum. Species with low cover-abundance scores were considered to have low constancy and not included. Introduced taxa are not included. Figure 3 shows a generalised map of vegetation distribution .

Community 1: *Eucalyptus olida* (Gibraltar Ash) – *Eucalyptus ligustrina* (Privet-leaved Stringybark) – *Eucalyptus cameronii* (Dichard Stringybark) forest and woodland

Habitat: associated with the Dandahra Granite. Found mainly on exposed to intermediate slopes in a range of topographic positions including crests and drainage lines, on sandy granitic soils above 900 m. Soils are shallow to skeletal.

Structure: heathy open forest and woodland or shrubland. Upper layer: 4–30 m; 10–40% cover. Upper middle layer: 2–8 m; 10–90% cover. Lower middle layer: 0.5–4 m; 15–80%; 0.1–2 m. Ground layer to 1 m, 10–90% cover.

Trees: *Eucalyptus olida, Eucalyptus ligustrina, Eucalyptus cameronii, Eucalyptus radiata* subsp. *sejuncta, Eucalyptus pyrocarpa, Eucalyptus oreades, Eucalyptus acaciiformis, Eucalyptus dalrympleana* subsp. *heptantha, Eucalyptus caliginosa, Eucalyptus williamsiana.*

Shrubs: *Leptospermum trinervium, Dillwynia phylicoides, Hakea laevipes* subsp. *graniticola, Petrophile canescens, Persoonia rufa, Daviesia umbellulata, Monotoca scoparia, Dampiera stricta, Boronia algida, Boronia microphylla, Banksia cunninghamii* subsp. A, *Patersonia sericea, Leucopogon melaleucoides, Melichrus procumbens, Grevillea acerata, Pimelea linifolia, Mirbelia speciosa, Comesperma ericinum, Styphelia triflora, Phyllota phylicoides, Acacia venulosa, Leptospermum polygalifolium, Acacia barringtonensis, Leucopogon* sp. aff. *appressus, Hibbertia riparia, Hibbertia villosa, Conospermum burgessiorum, Leucopogon microphyllus, Aotus subglauca.*

Climbers & trailers: *Billardiera scandens, Cassytha glabella, Cassytha pubescens.*

Ground cover: *Caustis flexuosa, Platysace ericoides, Bossiaea neo-anglica, Bossiaea scortechinii, Goodenia rotundifolia, Xanthorrhoea johnsonii, Entolasia stricta, Patersonia sericea, Gleichenia dicarpa, Dianella caerulea, Hovea heterophylla, Schoenus melanostachys, Lindsaea linearis, Trachymene incisa, Lepidosperma laterale, Gonocarpus teucrioides, Tetrarrhena juncea, Pteridium esculentum, Poa sieberiana, Lomandra filiformis, Lomandra longifolia.*

Variability: along drainage lines *Eucalyptus radiata* subsp. *sejuncta* is often the dominant tree. *Eucalyptus cameronii* and *Eucalyptus olida* are present in most sites, but are replaced by *Eucalyptus ligustrina* in more exposed situations with skeletal soils. The understorey species composition comprises a uniform cover of shrubs in particular *Leptospermum trinervium* and *Hakea laevipes* subsp. *graniticola.*

Notes: community 1 is the most widespread community throughout the study area. Closely-related assemblages in which *Eucalyptus olida-Eucalyptus ligustrina-Eucalyptus williamsiana- Eucalyptus cameronii* co- dominate have been recorded from the Timbarra Plateau, Malara State Forest, Gibraltar Range/Washpool and south to Guy Fawkes River NP. This association is generally found at high altitude in outcropping granite areas with skeletal soils.

Conservation status: community 1 is largely restricted to the study area and is reserved elsewhere within Guy Fawkes River and Nymboida NPs. Occurrences of related floristic assemblages on the Timbarra Plateau and north east of Tenterfield (the Desert) are not reserved within Demon NR or Basket Swamp NP (Hunter *et al.* 1999; Hunter 2005ab). It is likely however that the majority of its distribution is contained within reserves and is relatively extensive; it should be considered adequately reserved.

Community 2: *Eucalyptus olida* (Gibraltar Ash) – *Eucalyptus pyrocarpa* (Large-fruited Blackbutt) – *Eucalyptus planchoniana* (Needlebark Stringybark) forest and woodland

Habitat: granite sites on the plateau above 900 m. Usually found on exposed ridge tops and northerly to westerly slopes on the edge of the granite plateau on shallow to skeletal soils.

Structure: mostly dry open forest to low open woodland and mallee shrubland. Upper layer: 4–40 m; 15–50% cover. Middle layer: 1.5–10 m; 5–60% cover. Ground layer; 0.3–4 m; 20–80% cover.

Trees: *Eucalyptus olida, Eucalyptus pyrocarpa, Eucalyptus planchoniana, Eucalyptus cameronii, Eucalyptus codonocarpa, Eucalyptus caliginosa, Eucalyptus williamsiana, Eucalyptus oreades.*

Shrubs: *Leptospermum trinervium, Pultenaea tarik, Persoonia rufa, Acacia obtusifolia, Petrophile canescens, Monotoca scoparia, Banksia cunninghamii* subsp. A, *Leucopogon lanceolatus, Lomatia silaifolia, Amperea xiphoclada, Leucopogon melaleucoides, Boronia algida, Telopea aspera, Hibbertia villosa, Acacia novaanglica, Hibbertia riparia, Acacia ulicifolia, Phyllota phylicoides, Hakea laevipes* subsp. *graniticola, Boronia microphylla, Grevillea rhizomatosa, Choretrum candollei, Xanthosia pilosa, Podolobium ilicifolium, Grevillea acerata, Gompholobium latifolium, Elaeocarpus reticulatus, Dampiera purpurea, Acacia suaveolens.*

Climbers & trailers: *Billardiera scandens, Smilax glyciphylla, Cassytha pubescens, Cassytha glabella.*

Ground cover: *Platysace ericoides, Caustis flexuosa, Bossiaea scortechinii, Patersonia sericea, Entolasia stricta, Patersonia glabrata, Pteridium esculentum, Lepidosperma laterale, Dianella caerulea, Bossiaea neo-anglica, Xanthorrhoea johnsonii, Gonocarpus teucrioides, Lomandra longifolia, Lindsaea microphylla, Gonocarpus tetragynus, Goodenia rotundifolia, Gahnia microstachya, Cryptostylis subulata, Tetrarrhena juncea.*

Variability: structure varies considerably from tall open forests to mallee woodland. Three overstorey sub-associations are discernible in the field. Firstly sites in which *Eucalyptus olida* dominates. Secondly an association of *Eucalyptus planchoniana* and *Eucalyptus pyrocarpa* with or without *Eucalyptus olida* and *Eucalyptus williamsiana.* At high altitudes on the larger rock massifs mallee woodland merges with the taller woodlands within this assemblage.

Notes: as with Community 1, this assemblage is largely restricted to the Gibraltar Plateau on Dandahra Granite. Within Nymboida NP 583 ha occur along the common boundary with Gibraltar Range NP (Benwell 2000).

Conservation status: it is likely that this assemblage is almost entirely restricted to the study area with minor incursions into Nymboida National Park. This community should be considered rare and therefore of importance, however due to its almost complete restriction within the study region, it should be considered adequately reserved.

Community 3: *Baeckea omissa* (Baeckea) – *Epacris obtusifolia* (Blunt-leaf Heath) – *Leptospermum arachnoides* (Prickly Tea-tree) Bogs (Sedge Heaths)

Habitat: within areas of impeded drainage at high altitude on granite.

Structure: most commonly low closed heath or sedgeland but sometimes open woodland with emergent *Banksia marginata* or more rarely *Eucalyptus dissita* or *Eucalyptus ligustrina*. Shrub/sedge layer 0–2 m; 40–90% cover. Often a sparse ground cover (10%) of *Drosera spatulata, Goodenia bellidifolia* and *Gonocarpus micranthus*.

Trees: rarely emergent *Eucalyptus ligustrina, Eucalyptus dissita* or *Banksia marginata*.

Shrubs: *Baeckea omissa, Epacris obtusifolia, Leptospermum arachnoides, Banksia marginata, Hibbertia rufa, Epacris microphylla, Boronia polygalifolia, Prostanthera saxicola* var. *major, Hakea laevipes* subsp. *graniticola, Notelaea linearis, Grevillea acanthifolia* subsp. *stenomera, Dampiera stricta, Bauera rubioides, Mirbelia speciosa, Comesperma defoliatum, Brachyloma daphnoides* subsp. *glabrum*.

Climbers & trailers: *Cassytha glabella*.

Ground cover: *Lepidosperma limicola, Lepyrodia scariosa, Drosera spatulata, Baloskion fimbriatum, Amphipogon strictus, Xyris operculata, Entolasia stricta, Gonocarpus micranthus, Blandfordia grandiflora, Goodenia bellidifolia, Drosera binata, Tetrarrhena juncea, Gymnoschoenus sphaerocephalus, Logania pusilla, Lindsaea linearis, Thelionema caespitosum, Rhytidosporum diosmoides, Panicum paludosum, Lycopodium laterale, Hypericum gramineum, Drosera peltata, Boronia parviflora, Utricularia dichotoma, Trachymene incisa, Thelionema grande, Sphaerolobium vimineum, Schoenus turbinatus, Orthoceras strictum, Lepyrodia anarthria, Hybanthus monopetalus*.

Variability: this community has a number of species with high constance and many that were poorly associated, in particular many of the shrub taxa are ubiquitous (Hunter & Bell 2007). These communities are generally isolated, small and of limited distribution in the landscape and as such, although a number of species will usually be present and dominant the other associated taxa are likely to be highly variable. The community as defined here may be separated into indistinct bands of grass and cyperoid dominated areas along with shrubby patches. This is primarily driven by depth and duration of water logging which may vary from year to year (Hunter & Bell 2007). In a very few localities *Sphagnum* bogs have developed along small creek lines and may be only a few metres wide.

Notes: similar associations are restricted to higher altitudes on the tablelands particularly along the eastern margin of the divide and are included within Community 8 *Baeckea omissa – Epacris obtusifolia/ Lepidosperma limicola – Xyris operculata* Hunter & Bell (2007). This assemblage type is quite unlike other bogs of the Northern New England (Hunter & Bell 2007). Communities such as these are usually highly divergent across relatively small distances and as such most occurrences are unique. This proven by the community scoring the highest pattern diversity score of all communities measured (Table 1). Hunter and Bell (2007) have shown that this community is largely restricted to Gibraltar Range with an outlier on the Malara Plateau to the north.

Conservation status: broadly similar assemblages are known to be reserved within Warra NP, New England NP, Basket Swamp NP, Boonoo Boonoo NP, Bald Rock NP, Girraween NP, Demon NR, Cathedral Rocks NP, Mann River NR, Coolah Tops NP, western Washpool Western NP, Werrikimbe NP, Capoompeta NP and Butterleaf NP (Hunter *et al.* 1999; Hunter 2000; Whinam & Chilcott 2002; Hunter 2004b & c; Hunter 2005a & c; Hunter & Bell 2007). In the narrow sense however this assemblage type is known from the Demon NR, Gibraltar Range NP and Carrai NP and SCA (Hunter & Bell 2007). Benson and Ashby (2000) considered this type of assemblage to be moderately conserved within the state. Despite the above, areas which may develop peat are listed as endangered on the under the endangered ecological community *Montane peatlands and swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions* (17 December 2004) NSW *Threatened Species Conservation Act* (1995). Only a few surviving samples of communities containing significant amounts of *Sphagnum* are in good condition and it is likely that only a few hectares of these bogs occur across the whole tablelands (Whinam & Chilcott 2002; Hunter & Bell 2007).

Community 4: *Eucalyptus campanulata* (New England Blackbutt) – *Eucalyptus cameronii* (Die-hard Stringybark) forest and woodland

Habitat: all sites are located on Dandahra granite, predominantly on sheltered to intermediate aspects on mid to lower slopes in more exposed aspects or on upper slopes and ridge tops in sheltered to intermediate aspects at altitudes of 800–1000 m. This assemblage usually occurs down slope of communities 1 and 2 but above 7 and 10. Soils are deep to shallow sand or loam.

Table 1. Summary of selected attributes measured for each described community.

Community	Mean range size	Pattern diversity	Species density	Site richness range (average)	Number of sites	Area in ha (% of study area)	Number of species recorded
Community 1	14.7	0.423	39.1	29–54 (39)	22	6,826 (31)	156
Community 2	15.7	0.454	39.1	30–62 (39)	18	3,042 (14)	153
Community 3	14.9	0.446	20.9	12–26 (20)	7	567 (3)	50
Community 4	18.8	0.514	38.2	23–51 (38)	28	3,064 (14)	229
Community 5	13.7	NA	NA	25–32 (29)	2	2 (<0.1)	49
Community 6	16.8	NA	NA	20–45 (35)	3	2 (<0.1)	84
Community 7	17.4	NA	NA	21–22 (22)	2	27 (0.1)	31
Community 8	22.9	0.765	38.3	28–54 (43)	4	1,053 (5)	98
Community 9	20.3	0.477	42.6	39–48 (43)	4	1,054 (5)	82
Community 10	14.0	0.621	36.9	30–44 (37)	5	1,699 (8)	100
Community 11	13.4	0.595	30.4	19–35 (31)	5	1,058 (5)	79
Community 12	17.8	0.626	33.8	13–57 (29)	5	1,058 (5)	85
Community 13	17.7	0.440	35.7	25–47 (36)	25	2,373 (11)	164

Structure: tall open forests to dry open forests. Upper layer: 10–45 m; 25–50% cover. Upper middle layer: 2–20 m; 5–60% cover. Lower middle layer: 0.5–6 m, 15–80% cover. Ground layer: 0.1–1.5 m, 10–70% cover.

Trees: *Eucalyptus campanulata, Eucalyptus cameronii, Eucalyptus brunnea, Eucalyptus microcorys, Banksia integrifolia* subsp. *monticola, Allocasuarina torulosa, Allocasuarina littoralis, Eucalyptus obliqua, Eucalyptus olida, Corymbia intermedia, Eucalyptus caliginosa, Eucalyptus saligna, Eucalyptus notabilis, Eucalyptus oreades, Lophostemon confertus, Caldcluvia paniculosa.*

Shrubs: *Acacia nova-anglica, Dampiera purpurea, Leucopogon lanceolatus, Pultenaea tarik, Lomatia silaifolia, Polyscias sambucifolius, Acacia obtusifolia, Persoonia rufa, Hakea eriantha, Amperea xiphoclada, Elaeocarpus reticulatus, Podolobium aestivum, Choretrum candollei, Monotoca scoparia, Coopernookia chishomii, Boronia algida, Leucopogon melaleucoides, Leucopogon melaleucoides, Grevillea rhizomatosa, Trochocarpa laurina, Persoonia adenantha, Ozothamnus diosmifolius, Hibbertia riparia, Hibbertia aspera, Hakea salicifolia, Cryptocarya rigida, Hibbertia empetrifolia, Acrotriche aggregata, Acacia ulicifolia.*

Climbers & trailers: *Glycine clandestina, Hibbertia dentata, Billardiera scandens, Hibbertia scandens, Eustrephus latifolins, Kennedia rubicunda, Hardenbergia violacea, Desmodium varians, Cissus hypoglauca, Clematis aristata, Clematis glycinoides, Smilax glyciphylla, Pandorea pandorana, Geitonoplesium cymosum, Rubus parviflorus, Palmeria scandens, Muehlenbeckia gracillima, Morinda jasminoides, Desmodium rhytidophyllum, Desmodium gangeticum,. Cissus antarctica.*

Ground cover: *Calochlaena dubia, Pteridium esculentum, Imperata cylindrica, Lomandra longifolia, Dianella caerulea, Gonocarpus teucrioides, Entolasia stricta, Poa sieberiana, Viola betonicifolia, Viola hederacea, Blechnum cartilagineum, Patersonia glabrata, Lepidosperma urophorum, Platysace ericoides, Lepidosperma laterale, Lagenifera gracilis, Corybas aconitiflorus, Bossiaea scortechinii, Opercularia hispida, Sorghum leiocladum, Patersonia sericea, Tetrarrhena juncea, Hydrocotyle peduncularis, Goodenia rotundifolia, Gonocarpus tetragynus, Xanthorrhoea glauca, Sticherus lobatus, Pomax umbellata, Lomandra confertifolia, Lepidosperma elatius, Goodenia hederacea, Geranium solanderi, Cyathea australis.*

Variability: there are three field definable overstorey floristic sub-assemblages. The first and most widespread is a tall open forest dominated by *Eucalyptus campanulata*, with a tall shrub layer of *Acacia nova-anglica*, a dense low shrub layer of *Pultenaea sp* 'Gibraltar Range' and a ground layer of grass and ferns. The second sub-association of *Eucalyptus obliqua* with a mesic middle layer of tree ferns and a dense ground layer of water and bracken fern. The third sub-association is of a dry open forest dominated by *Eucalyptus campanulata* with *Corymbia intermedia* and *Allocasuarina torulosa* as a small tree layer, with a sparse shrub layer and a dense cover of ferns and herbs.

Notes: *Eucalyptus campanulata* has an almost ten-fold greater cover than the nearest tree in this grouping. The assemblage is allied to Beadles' (1981) *E. campanulata* Alliance that is described as occurring at higher altitudes from just over the Queensland border to the Barrington Tops area (McDonald & Whiteman 1979; Binns & Chapman 1993; Binns 1995a & b; Hunter 2004; 2005a & c). All described occurrences are at altitudes above 900 m. Binns (1995b) considered this association as possibly the most widespread community in the Tenterfield district above 900 m on all geological substrates. Clarke *et al.* (1998) describe a slightly divergent but very similar community as occurring on a metasediment pendant at Torrington.

Conservation status: this assemblage is well-represented locally and across its range. Despite being fairly extensive in the broad sense, as described here the assemblage is probably fairly restricted and centred on the escarpment from Guy Fawkes River north to the Timbarra Plateau. It is well reserved in Nymboida NP (3,530ha) (Benwell 2000), western areas of Washpool NP (9,363 ha) (Hunter 2005), Mann River NR (1,834 ha) (Hunter 2004), Guy Fawkes River NP (6,783 ha) (Hunter & Alexander 1999), Basket Swamp NP (1,059 ha) (Hunter 2004c) and the present study area (3,064ha).

Community 5: *Eucalyptus oreades* (Blue Mountains Ash) – *Eucalyptus campanulata* (New England Blackbutt) woodland and shrubland

Habitat: restricted to fugitive outcrops particularly in riparian areas.

Structure: upper layer: 8–30 m; 10–30% cover; Upper mid layer: 4–10 m; 5–60% cover. Lower mid layer: 1–4 m; 30–50% cover. Ground layer: <1 m, 10–30% cover.

Trees: *Eucalyptus oreades, Eucalyptus campanulata, Ceratopetalum apetalum, Banksia integrifolia* subsp. *monticala.*

Shrubs: *Leionema dentatum, Pultenaea tarik, Prostanthera caerulea, Persoonia rufa, Leptospermum novae-angliae, Dillwynia rupestris, Leptospermum trinervium, Kunzea bracteolata, Hakea salicifolia, Epacris longiflora, Cassinia aureonitens, Brachyloma saxicola, Boronia angustisepala, Polyscias sambucifolius, Orites excelsa, Lomatia silaifolia, Leucopogon lanceolatus, Elaeocarpus reticulatus, Comesperma ericinum, Callitris monticola, Boronia anethifolia, Bauera rubioides, Alyxia ruscifolia, Allocasuarina rigida* subsp. *rigida.*

Climbers & trailers: *Smilax australis, Billardiera scandens.*

Ground cover: *Schoenus melanostachys, Lepidosperma urophorum, Lepidosperma laterale, Pteridium esculentum, Lomandra longifolia, Gonocarpus teucrioides, Dianella caerulea, Caustis flexuosa, Trachymene incisa, Thelionema grande, Patersonia sericea, Laxmannia compacta, Gleichenia dicarpa, Gahnia sieberiana, Entolasia stricta, Calochlaena dubia, Blechnum cartilagineum, Asplenium flabellifolium.*

Variability: the two sampled sites vary structurally but are share many taxa including the overstorey dominants. *Eucalyptus oreades* is generally restricted in extent in the study area and is usually associated with riparian areas on the granitic plateau.

Notes: overstorey associations of *Eucalyptus oreades* have been recorded in disjunct occurrences from the Border Ranges NP to Werrikimbe NP. These other occurrences, however, differ considerably in understorey floristics compared to those recorded in Community 5.

Conservation status: this is one of the most limited communities within the reserve. The assemblage should be considered vulnerable due to its limited occurrence. Its full extent appears to be completely within the study area, although a somewhat similar grouping of taxa is known to occur in a limited area on rock outcrops in Basket Swamp NP (Hunter 2004c).

Community 6: *Callicoma serratifolia* (Black Wattle) – *Eucalyptus oreades* (Blue Mountains Ash) open forest and shrubland

Habitat: restricted to open granite surfaces or fugitive outcrops in riparian areas.

Structure: shrubby open forest or shrubland.

Trees: *Callicoma serratifolia, Eucalyptus oreades, Ceratopetalum apetalum.*

Shrubs: *Leptospermum polygalifolium, Callistemon pallidus, Callistemon sieberi, Prostanthera caerulea, Hakea salicifolia, Bauera rubioides, Baeckea omissa, Allocasuarina rigida* subsp. *rigida, Acacia venulosa, Prostanthera scutellarioides, Leptospermum trinervium, Hibbertia rufa, Epacris obtusifolia, Epacris microphylla, Acacia floribunda.*

Climbers & trailers: *Billardiera scandens, Cassytha glabella.*

Ground cover: *Gleichenia dicarpa, Sticherus lobatus, Schoenus melanostachys, Tetrarrhena juncea, Pteridium esculentum, Lepyrodia scariosa, Gonocarpus teucrioides, Entolasia stricta, Drosera spatulata, Drosera binata, Corybas aconitiflorus, Chiloglottis silvestris, Blechnum cartilagineum.*

Variability: the two sampled sites vary structurally but are share many taxa including the overstorey dominants. *Eucalyptus oreades* is generally restricted in extent in the study area and is usually associated with shallow soils in riparian areas on the granitic plateau.

Notes: overstorey associations of *Eucalyptus oreades* have been recorded in disjunct occurrences from the Border Ranges NP to Werrikimbe NP. These other occurrences, however, differ considerably in understorey floristics compared to those recorded here.

Conservation status: this is a very limited community within the reserve. The assemblage should be considered vulnerable due to its limited occurrence. Similar diverse shrubby communities area described for riparian margins on granite in Warra, Basket Swamp and Washpool (western) NPs (Hunter 1998; Benson and Ashby 2000; Hunter 2004c; Hunter 2005c).

Community 7: *Leptospermum petersonii* subsp. *petersonii* (Lemon-scented Tea-tree) – *Phebalium squamulosum* subsp. *squamulosum* (Phebalium) closed scrub.

Habitat: at high altitude on sedimentary rocks.

Structure: closed scrub. Upper layer: 4–18 m; 70% cover. Middle layer: to 8 m; 30% cover. Ground layer: <1.5 m, 20–80% cover.

Shrubs: *Leptospermum petersonii* subsp. *petersonii, Phebalium squamulosum* subsp. *squamulosum, Banksia integrifolia* subsp. *monticola, Alyxia ruscifolia, Leucopogon lanceolatus, Trochocarpa laurina, Tasmannia insipida, Zieria smithii, Notelaea longifolia, Acmena smithii.*

Climbers & trailers: *Pyrrosia rupestris, Hibbertia scandens, Pandorea pandorana, Cissus hypoglauca, Rubus nebulosus, Rubus moluccanus, Parsonsia straminea.*

Ground cover: *Lomandra longifolia, Hydrocotyle peduncularis, Dianella caerulea, Asplenium flabellifolium, Oplismenus aemulus, Carex appressa, Galium propinquum, Aneilema acuminatum, Plectranthus parviflorus, Oplismenus imbecillis, Histiopteris incisa, Davallia solida* var. *pyxidata, Asplenium australasicum.*

Variability: though varying in structure both sites were floristically very similar.

Notes: this assemblage is included within Floyd's (1990) sub-alliance 46 and is described as a closed scrub community characterised by the occurrence of *Leptospermum* spp. *Notelaea venosa* and *Prostanthera* spp. Such closed scrubs are described as occurring on high altitude ridge tops with shallow soils in seasonally dry locations (Floyd 1990) such as the summit of Wilson's Peak, Mt Lindesay, Mt Warning and on high exposed aspects in Washpool NP, including Hayden's Trig. It differs from other occurrences of sub alliance 46 at Mt Nothofagus, New England NP, and Werrikimbe NP, due to the absence of *Cryptocarya nova-anglica* and at Mt Hyland, Dorrigo Escarpment by the replacement of *Leptospermum petersonii* with *Leptospermun polygalifolium.* Some broadly synonymous assemblages at high altitudes dominated by *Leptospermum petersonii* have been described within New England NP and further south within the Kempsey/Wauchope area (Binns & Chapman 1993).

Conservation status: in the broad sense Community 6 is reserved in the Border Ranges, Washpool, Gibraltar Range and Mt Warning NPs. In the strict sense, there appears to be a significant structural and floristic variation within sub-alliance 46, which requires more detailed study. It should be considered vulnerable due to its limited extent.

Community 8: *Eucalyptus biturbinata* (Grey Gum) – *Lophostemon confertus* (Brush Box) woodland and forest

Habitat: lower to mid slopes (300–900 m) on the eastern escarpment on sedimentary soils.

Structure: grassy open forest or woodland. Upper layer: 8–30 m; 10–45% cover. Upper mid layer: 10–15 m, 20–55% cover. Lower mid layer: 2–6 m; 10–30%. Ground layer: < 2 m; 40–90% cover.

Trees: *Eucalyptus biturbinata, Lophostemon confertus, Allocasuarina torulosa, Eucalyptus saligna, Eucalyptus pyrocarpa, Eucalyptus microcorys, Eucalyptus fibrosa, Eucalyptus carnea, Eucalyptus campanulata, Eucalyptus acmenoides.*

Shrubs: *Ricinocarpos speciosus, Persoonia sericea, Persoonia oleoides, Ozothamnus diosmifolius, Monotoca scoparia, Maytenus bilocularis, Lomatia silaifolia, Leucopogon lanceolatus, Indigofera australis, Clerodendrum tomentosum, Brachyloma daphnoides* subsp. *glabrum, Acacia melanoxylon.*

Climbers & trailers: *Desmodium varians, Rubus parviflorus, Hibbertia scandens, Hardenbergia violacea, Glycine tabacina, Glycine clandestina, Eustrephus latifolius, Desmodium rhytidophyllum, Desmodium brachypodum, Commelina cyanea, Cissus hypoglauca.*

Ground cover: *Poa sieberiana, Imperata cylindrica, Xanthorrhoea glauca, Viola betonicifolia, Vernonia cinerea, Senecio prenanthoides, Pratia purpurascens, Plectranthus parviflorus, Lomandra longifolia, Helichrysum scorpioides, Goodenia bellidifolia, Entolasia stricta, Dichondra repens, Dianella caerulea, Cymbopogon refractus, Cheilanthes sieberi, Arthropodium milleflorum, Wahlenbergia luteola, Viola hederacea, Veronica calycina, Trachymene incisa, Themeda triandra, Stackhousia viminea, Senecio quadridentatus, Senecio lautus, Senecio amygdalifolius, Ranunculus lappaceus, Pteris tremula, Pteridium esculentum, Pseuderanthemum variabile, Pomax umbellata, Polygala japonica, Plantago debilis, Pellaea falcata, Panicum simile, Oxalis exilis, Oplismenus imbecillis, Oplismenus aemulus, Opercularia hispida, Lomandra multiflora, Lomandra filiformis, Lagenifera gracilis, Hypericum gramineum, Hydrocotyle peduncularis, Hydrocotyle laxiflora, Haloragis heterophylla, Gonocarpus teucrioides, Gonocarpus tetragynus, Geranium solanderi, Euchiton sphaericus, Eragrostis brownii, Echinopogon caespitosus, Doodia aspera, Dichelachne micrantha, Capillipedium spicigerum, Botrychium australe, Asplenium flavellifolium.*

Variability: it is likely that this assemblage was under-sampled. *Lophostemon confertus* becomes more dominant in gullies and in other protected localities.

Notes: this assemblage appears to be broadly related to grassy to shrubby foothill and escarpment woodlands or forests that occur from the Queensland border to the Hunter region.

Conservation status: in the broadest terms this community appears to be represented within reserves across its range and locally is well represented within the study area and also potentially within Nymboida NP (10,645 ha) (Benwell 2000), Washpool (western) NP (4,578 ha) (Hunter 2005), Mann River NR (1,737 ha) (Hunter 2004) and within Guy Fawkes River NP (2,555 ha) (Hunter & Alexander 1999).

Community 9: *Eucalyptus carnea* (Thick-leaved Mahogany) – *Syncarpia glomulifera* (Turpentine) – *Corymbia intermedia* (Pink Bloodwood) forest and woodland

Habitat: on granite at lower altitudes (300–400 m), upper to lower slopes on exposed, intermediate and sheltered slopes.

Structure: grassy dry open forest. Upper layer: 18–35 m; 25–45% cover. Upper mid layer often present: 5–16 m; to 25% cover. Lower mid layer: 1.5–7 m; 35–55% cover. Ground layer: to 2 m; 70–80% cover.

Trees: *Eucalyptus carnea, Syncarpia glomulifera, Corymbia intermedia, Allocasuarina torulosa, Eucalyptus microcorys, Eucalyptus pyrocarpa, Eucalyptus planchoniana, Eucalyptus biturbinata, Lophostemon confertus.*

Shrubs: *Leucopogon juniperinus, Dodonaea triquetra, Acacia blakei, Hibbertia obtusifolia, Persoonia adenantha, Jacksonia scoparia, Trochocarpa laurina, Pimelea linifolia, Orites excelsa, Dampiera purpurea, Acrotriche aggregata.*

Climbers & trailers: *Desmodium rhytidophyllum, Desmodium varians, Glycine clandestina, Hardenbergia violacea, Pandorea pandorana, Hibbertia scandens, Geitonoplesium cymosum, Cassytha glabella.*

Ground cover: *Deyeuxia parviseta, Oplismenus imbecillis, Vernonia cinerea, Panicum simile, Opercularia hispida, Lepidosperma laterale, Imperata cylindrica, Pomax umbellata, Lomandra confertifolia, Lagenifera gracilis, Eragrostis brownii, Entolasia stricta, Dianella caerulea, Glossogyne tannensis, Digitaria parviflora, Cymbopogon refractus, Corybas aconitiflorus, Cheilanthes sieberi, Aristida queenslandica, Pterostylis nutans, Phyllanthus virgatus, Oplismenus aemulus, Lomandra multiflora, Lomandra filiformis, Lepidosperma urophorum, Goodenia hederacea, Brunoniella pumilio, Adiantum hispidulum.*

Variability: there are a range of overstorey associations that occur within this assemblage in which either *Syncarpia glomulifera, Eucalyptus carnea* and/or *Eucalyptus microcorys* may dominate.

Conservation status: in the broadest terms this community appears to be represented within reserves across its range such as at Nymboida NP. [10645 ha] (Benwell 2000), Western Washpool NP [2828 ha] (Hunter 2000) and Guy Fawkes NP (Hunter & Alexander 1999).

Community 10: *Eucalyptus campanulata* (New England Blackbutt) – *Eucalyptus microcorys* (Tallowwood) open forest

Habitat: on sedimentary or acid volcanic rock types from 300–1000+ m. Usually on intermediate to sheltered aspects with deep soils.

Structure: tall open forest. Upper layer: 25–45 m; 30–45% cover. Upper mid layer: 4–20 m; 15–40% cover. Lower mid layer: 1–8 m; 15–80% cover. Ground layer: <1 m; 10–60% cover.

Trees: *Allocasuarina torulosa, Eucalyptus campanulata, Eucalyptus microcorys, Caldcluvia paniculosa, Lophostemon confertus, Eucalyptus carnea, Schizomeria ovata, Banksia integrifolia* subsp. *monticola, Syncarpia glomulifera, Eucalyptus saligna, Eucalyptus obliqua, Eucalyptus caliginosa.*

Shrubs: *Trochocarpa laurina, Acacia irrorata, Elaeocarpus reticulatus, Lomatia silaifolia, Leucopogon lanceolatus, Archirhodomyrtus beckleri, Zieria smithii, Archontophoenix cunninghamiana, Acacia nova-anglica, Wilkiea huegeliana, Synoum glandulosum, Polyscias sambucifolius, Pittosporum undulatum, Endiandra sieberi.*

Climbers & trailers: *Palmeria scandens, Hibbertia dentata, Smilax glyciphylla, Smilax australis, Cissus hypoglauca, Eustrephus latifolius, Hibbertia scandens, Rubus nebulosus, Parsonsia induplicata, Glycine clandestina, Geitonoplesium cymosum, Billardiera scandens, Streptothamnus moorei, Piper novae-hollandiae, Morinda jasminoides, Parsonsia velutina, Marsdenia rostrata, Desmodium gangeticum, Cephalaralia cephalobotrys.*

Ground cover: *Lomandra longifolia, Calochlaena dubia, Oplismenus aemulus, Lepidosperma laterale, Dianella caerulea, Blechnum cartilagineum, Viola hederacea, Lepidosperma elatius, Gonocarpus oreophilus, Gahnia aspera, Xanthorrhoea glauca, Pteridium esculentum, Oplismenus imbecillis, Lobelia trigonocaulis, Galium propinquum, Entolasia stricta, Doodia aspera, Cyperus disjunctus, Corybas aconitiflorus.*

Variability: at higher altitudes *Eucalyptus campanulata* dominates in association with *Eucalyptus microcorys* while at lower altitudes *Eucalyptus carnea* may become more prominent along with an occasional occurrence of *Eucalyptus crebra* or *Eucalyptus tereticornis* particularly along drainage lines.

Notes: this community appears to be intermediate between many currently described associations with *E. campanulata, E. microcorys* and *E. saligna* as dominants. Differences with other similar communities in the north-east of New South Wales are the lack of dominant and closed mesomorphic understorey of rainforest taxa and few or no sclerophyll species. Communities with similar overstorey components are described by Young and McDonald (1989) with a patchy distribution on the McPherson Range along the Queensland/New South Wales Border near Mount Nothofagus and Mount Ernest. In the survey of the Demon Nature Reserve a similar forest is described with a more or less prominent mesomorphic understorey fringing closed forests (Hunter *et al.* 1999). Binns (1995e) describes a similar community in the Casino Management Area. Binns & Chapman (1993) also describe a somewhat similar community in the Kempsey-Wauchope area. From these accounts it is likely that similar, if not the same floristic associations, may occur from as far north as the McPherson Ranges along the Queensland border along the edge of the escarpment to as far south as Clouds Creek or possibly to the Wauchope and Kempsey region. As described here however this assemblage is largely restricted to the Washpool to northern Guy Fawkes River region. In the strictest sense, this assemblage appears to be largely centred around the study region with a few occurrences extending not far north or south.

Conservation status: well reserved locally e.g. Washpool (western) NP (2,075 ha) (Hunter 2005), Nymboida NP (3,530 ha, possibly a further 6388 ha) (Benwell 2000) and Guy Fawkes NP (northern section; 1,031 ha) (Hunter & Alexander 1999). This assemblage should be considered adequately reserved.

Community 11: *Cryptocarya rigida* (Forest Maple) – *Synoum glandulosum* (Scentless Rosewood) closed forest

Habitat: sediment and acid volcanic rock types above 700 m. Soils are deep clay loams.

Structure: Emergent layer: 20–50 m; 20–40% cover. Closed forest layer: 4–25 m; 60–80% cover. Ground cover: < 2 m; 15–20% cover.

Trees: *Cryptocarya rigida, Archontophoenix cunninghamiana, Synoum glandulosum, Sloanea woollsii, Orites excelsa, Lophostemon confertus, Eucalyptus saligna, Eucalyptus microcorys, Eucalyptus campanulata, Cryptocarya obovata, Caldcluvia paniculosa.*

Shrubs: *Tasmannia insipida, Trochocarpa laurina.*

Climbers & trailers: *Parsonsia velutina, Palmeria scandens, Morinda jasminoides, Cephalaralia cephalobotrys, Tylophora paniculata, Smilax glyciphylla, Smilax australis, Rubus nebulosus, Piper novae-hollandiae, Parsonsia induplicata, Pandorea pandorana, Legnephora moorei, Eustrephus latifolius, Clematis glycinoides, Clematis aristata.*

Ground cover: *Lomandra spicata, Linospadix monostachya, Lastreopsis microsora, Blechnum cartilagineum.*

Variability: this structurally divergent assemblage commonly straddles the ecotone between open forest and closed forest at higher altitudes and thus usually contains a dense closed forest understorey with various overstorey eucalypt taxa.

Conservation status: similar assemblages are considered adequately reserved across their range at present.

Community 12: *Ceratopetalum apetalum* (Coachwood) – *Caldcluvia paniculosa* (Soft Corkwood) closed forest

Habitat: on granite usually at high altitudes on lower to mid slopes in sheltered to intermediate aspects.

Structure: Upper layer: 15–55 m; 80% cover. Mid layer rarely present: 1–6 m; 70%. Ground cover: < 1m; 20–40% cover.

Trees: *Ceratopetalum apetalum, Caldcluvia paniculosa, Sloanea woollsii, Quintinia sieberi, Orites excelsa, Endiandra sieberi, Endiandra discolor, Callicoma serratifolia, Cryptocarya meissneriana, Callicoma serratifolia, Anopterus macleayanus, Acradenia euodiiformis.*

Shrubs: *Citriobatus pauciflorus, Tasmannia insipida.*

Climbers & trailers: *Smilax australis, Parsonsia induplicata, Palmeria scandens, Morinda jasminoides, Tylophora paniculata, Rubus moluccanus, Pandorea pandorana, Marsdenia rostrata, Hibbertia scandens, Eustrephus latifolius, Clematis glycinoides, Cissus hypoglauca, Cephalaralia cephalobotrys.*

Ground cover: *Microsorum scandens, Lomandra spicata, Lobelia trigonocaulis, Linospadix monostachya, Histiopteris, incisa, Cyathea australis, Carex appressa, Asplenium australasicum.*

Variability: in general this association would be included within sub alliance 35 of Floyd (1990) though at some localities the assemblage is more like sub-alliance 33.

Conservation status: similar assemblages are considered adequately reserved across their range at present.

Community 13: *Kunzea bracteolata* (Granite Kunzea) – *Leptospermum nova-angliae* (New England Tea-tree) heaths and shrubland

Habitat: restricted to exposed granitic outcrops, particularly on sheet granite where the community grows within crevices, cracks and shallow soil islands, but may occasionally occur in a shallow soil skirt around the margins of outcrops.

Structure: mainly closed heaths although the mallee *Eucalyptus codonocarpa* may be present forming shrubby open scrubs (mallee). Occasionally other trees species occur, such as *Eucalyptus campanulata, Eucalyptus olida, Eucalyptus caliginosa*, giving a shrubby low open woodland structure. In some instances *Leptospermum novae-angliae* at its tallest and densest will form closed scrub.

Trees: *Eucalyptus codonocarpa, Eucalyptus notabilis, Eucalyptus ligustrina, Eucalyptus cameronii, Eucalyptus radiata* subsp. *sejuncta, Eucalyptus acaciiformis.*

Shrubs: *Kunzea bracteolata, Leucopogon neoanglicus, Leptospermum novae-angliae, Boronia anethifolia, Calytrix tetragona, Callistemon comboynensis, Allocasuarina rigida* subsp. *rigida, Acacia suaveolens, Mirbelia confertiflora, Grevillea acerata, Epacris microphylla, Phebalium squamulosum, Ozothamnus diosmifolius, Dampiera stricta, Leptospermum trinervium, Acacia brunioides* subsp. *brunioides, Mirbelia rubiifolia, Brachyloma saxicola, Pseudanthus pauciflorus* subsp. *pauciflorus, Persoonia rufa, Callitris monticola.*

Climbers & trailers: *Cassytha filiformis, Smilax glyciphylla, Smilax australis.*

Ground cover: *Lepidosperma laterale, Lepidosperma gunnii, Trachymene incisa* var. *incisa, Entolasia stricta, Laxmannia compacta, Brachyscome stuartii, Lomandra longifolia, Schoenus melanostachys, Aristida ramosa, Xanthorrhoea glauca, Schoenus apogon, Platysace ericoides, Lepyrodia scariosa, Austrodanthonia richardsonii, Gonocarpus teucrioides, Caustis flexuosa, Austrostipa scabra, Goodenia bellidifolia, Gahnia sieberiana, Bulbostylis densa, Tetrarrhena juncea, Lepidosperma neesii, Gonocarpus oreophilus, Cheilanthes sieberi.*

Variability: The small population sizes and the harsh environment afforded by the rock outcrop habitat necessarily means that even adjacent occurrences are likely to contain very different species assemblages (Hunter 2000a; Hunter 2002; Hunter 2003a; Hunter 2004a). Although a few species may be dominant in most situations they may inexplicably be missing, at least above ground, from nearby sites. Disturbances such as fire can dramatically change the floristics and structure temporarily as a suite of short lived disturbance ephemerals establish (Hunter 1995; Hunter 1998a; Hunter *et al.* 1998; Hunter 2003b).

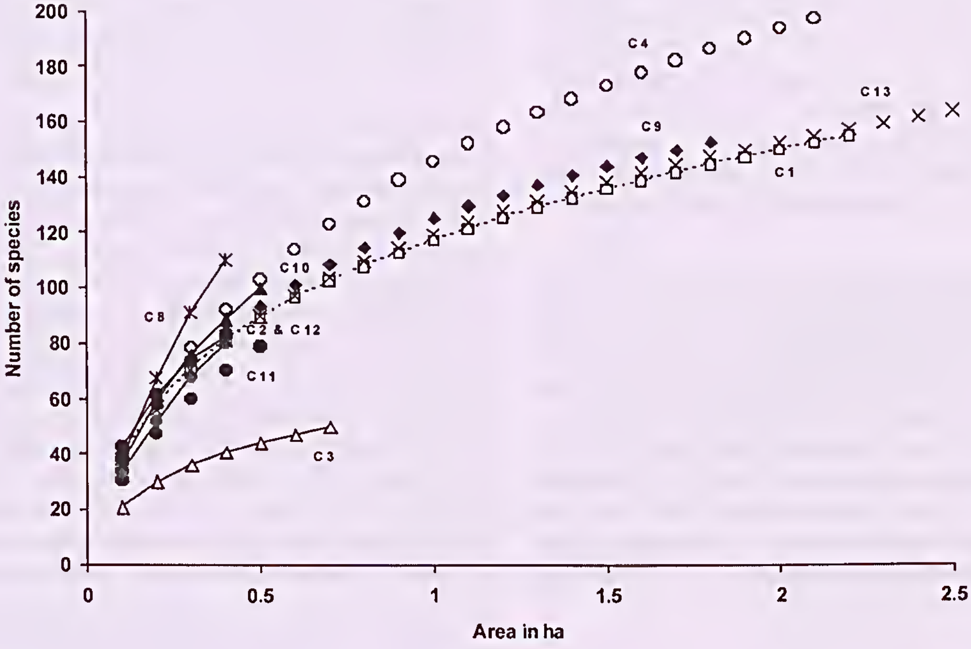

Fig. 4. Rarefaction curves for each community with at least four sample sites.

Notes: this grouping includes three of the nine elements of granitic outcrop vegetation delineated by Hunter and Clarke (1998). Two of these elements are only sparingly represented within the reserve, with the majority of the rock outcrop communities within Gibraltar Range constituting Element 3 of Hunter and Clarke (1998). This element and its single constituent community are entirely restricted to Gibraltar Range. This endemic community, though quite divergent, is broadly related to other outcrop associations that occur along the eastern escarpment of the New England Batholith from Cathedral Rocks to Boonoo Boonoo (Hunter and Clarke 1998).

Conservation status: considered adequately reserved and well represented both locally and across its range, and currently not under any considerable threat. The assemblage is largely restricted to Gibraltar Range NP.

Community attributes

Species accumulation varied greatly across communities (Fig. 4). The highest accumulating curve was achieved by Community 8 (*Eucalyptus biturbinata – Lophostemon confertus*) followed by Community 4 (*Eucalyptus campanulata*) and Community 10 (*Eucalyptus campanulata – E. microcorys*). The least accumulating curve was Community 3 (*Baeckea omissa – Epacris obtusifolia*) which was substantially lower than all others measured, with second lowest being Community 11 (*Cryptocarya rigida – Synoum glandulosum*). At the level of four sample sites (0.4 ha) it is expected that Community 3 will contain 41 taxa and Community 8, 110 taxa. Modelled species density however was highest within Community 9 (*Eucalyptus carnea – Eucalyptus microcorys*) with 42.6 taxa per 0.1 ha (Table 1). This is in contrast to the Community 3 (*Baeckea omissa – Epacris obtusifolia*) which contained only 20.9 taxa per 0.1 ha. Spatial turnover within communities (pattern diversity) was also highly variable with Community 8 (*Eucalyptus biturbinata – Lophostemon confertus*) having almost twice as much turnover compared to Community 1 (*Eucalyptus olida – E. ligustrina – E. carnea*) and Community 13 (*Kunzea bracteolata – Leptospermum novae angliae*) (Table 1). Comparatively high turnover was also found within Community 10 (*Eucalyptus campanulata – E. microcorys*), Community 11 (*Cryptocarya rigida – Synoum glandulosum*) and Community 12 (*Ceratopetalum apetalum– Caldcluvia paniculosa*).

Cumulative species occupancy as measured by average geographic range size was highest in community 13 (*Kunzea bracteolata – Leptospermum novae angliae*) followed by community 8 (*Eucalyptus biturbinata – Lophostemon confertus*) and community 9 (*Eucalyptus carnea – Syncarpia glomulifera – Corymbia gummifera*) (Table 1). The lowest average range size was obtained by Community 11 (*Cryptocarya rigida – Synoum glandulosum*) and then Community 5 (*Eucalyptus oreades – E. campanulata*) and Community 10 (*Eucalyptus campanulata – E. microcorys*) (Table 1).

Rare and threatened species

81 species of special conservation significance were recorded from Gibraltar Range National Park and the southern section of Washpool National Park (Table 2). Seven taxa are listed or should be considered for listing on the *NSW Threatened Species Conservation Act* 1995, including five listed as endangered and two vulnerable (Table 2). 35 species are listed in Briggs and Leigh (1996) as 'Rare or Threatened Australian Plants' (ROTAPs) or have since been coded and published by other authors according to ROTAP criteria (Table 2). A further 40 species are considered to be of regional or local conservation significance according to Sheringham and Westaway (1995) (Table 2).

Discussion

Significance and conservation issues

The total of 878 taxa recorded within the study area (Gibraltar Range & southern Washpool NPs) represents a relatively high species richness and is similar to that found for other recently surveyed large reserves on the eastern escarpment (Hunter 1998b; Hunter 2004b; Benwell 2000). The vegetation reflects its placement within the north east of New South Wales. Many of the major assemblages along the eastern escarpment of the Northern Tablelands have distributions that range from just over the border in Queensland to Barrington in New South Wales. Gibraltar Range lies almost in the centre of this distribution pattern. It is not surprising therefore that many of the communities circumscribed herein, in the strict sense, radiate from the study area north and south and in the broad sense occur as far north as the Queensland border and as far south as Barrington. It is also not surprising that several communities are apparently endemic to the study area, with few correlates, even in the broad sense, occurring elsewhere.

Approximately 60% of the woody vegetation in the New England Bioregion has been cleared (Benson 1999). Half of the communities described for the study area (Communities 1, 2, 5, 6 and 7) are endemic, or almost exclusively restricted to, to the area including Community 1 which is the most widespread of those mapped. Communities 1, 4 and 10 are considered rare, in terms of distributional extent, and Communities 5 and 7 should be considered as vulnerable, due to their very limited natural distribution. Despite half of these assemblages being rare in the landscape, all are considered to be adequately reserved, as much of their natural extent is currently within conservation reserves. The remaining communities are thought to radiate further north and south from the study area, but with significant local variation that is centred, in terms of distribution, within the study area.

81 species of special conservation significance have been recorded from Gibraltar Range National Park and southern section of Washpool National Park representing 10% of the

Table 2. Summary of rare, threatened and regionally uncommon species. Codes in brackets are suggested but not yet ratified. Upper North East Codes are those given by Sheringham and Westaway (1995).

Taxon	TSC Act Listing	RoTAP Code	Upper NE NSW Code
1: Eucalyptus dissita	Endangered	2RC-	-
2: Grevillea mollis	Endangered	2ECi	-
3. Hibbertia rhynchocalyx	[Endangered]	[2ECi]	-
4: Marsdenia longiloba	Endangered	3RC-	-
5: Tylophora woollsii	Endangered	2E	-
6: Cryptostylis hunteriana	Vulnerable	3VC-	-
7: Grevillea rhizomatosa	Vulnerable	2VC-t	-
8. Solanum nobile	-	3VC-	-
9: Acacia barringtonensis	-	3RCa	-
10: Acacia beadleana	-	2VCit	-
11: Acacia brunioides subsp. *brunioides*	-	3RC-	[Disjunct]
12: Acacia cangaiensis	-	2RC-	-
13: Boronia angustisepala	-	2RCa	-
14: Brachyloma saxicola	-	2RCa	-
15: Callitris monticola	-	3RC-	-
16: Chiloglottis sphyrnoides	-	3KC-	-
17: Conospermum burgessiorum	-	3RCa	-
18: Cryptandra lanosiflora	-	3RCa	-
19: Dillwynia rupestris	-	3RC-t	-
20: Dodonaea serratifolia	-	2RC-	-
21: Eucalyptus codonocarpa	-	3RC-	-
22: Eucalyptus olida	-	2RCa	-
23: Grevillea acanthifolia subsp. *stenomera*	-	3RC-	-
24: Grevillea acerata	-	2RC-t	-
25: Hakea macrorhyncha	-	[3RC-]	-
26: Keraudrenia corollata var. *denticulata*	-	3RC-	-
27: Kunzea bracteolata	-	3RC-	-
28: Marsdenia liisae	-	3RC-	-
29: Leionema ambiens	[Vulnerable]	3RC- [3VC-]	-
30: Melaleuca tortifolia	-	2RC-t	-
31: Podolobium aestivum	-	3RC-	-
32: Persoonia rufa	-	2RCa	-
33: Pultenaea pycnocephala	-	3RCa	-
34: Pultenaea sp. B	-	2RC-t	-
35: Ricinocarpos speciosus	-	3RCi	-
36: Telopea aspera	-	2RCa	-
37: Thelionema grande	-	3RC	-
38: Westringia sericea	-	3RC-	-
39: Hibbertia villosa	-	3KC-	-
40: Plectranthus suaveolens	-	3KC-	-
41: Acacia mitchellii	-	-	Disjunct; Northern Limit
42: Acianthus caudatus	-	-	Regionally Rare; Northern Limit
43: Actinotus gibbonsii	-	-	Regionally Rare
44: Bulbophyllum bracteatum	-	-	Rare in NSW; Southern Limit
45: Caladenia alata	-	-	Regionally Rare
46: Callistemon sp. 'Big Red'	-	-	Regionally Rare
47: Callistemon linearis	-	-	Regionally Rare; Disjunct
48: Callitriche muelleri	-	-	Regionally Rare
49: Cassinia aureonitens	-	-	Regionally Rare; Disjunct; Northern Limit
50: Cassinia compacta	-	-	Regionally Rare; Endemic
51: Coopernookia barbata	-	-	Regionally Rare; Northern Limit
52: Correa lawrenciana var. *glandulifera*	-	-	Regionally Rare
53: Daviesia wyattiana	-	-	Disjunct; Northern Limit
54: Euphrasia collina subsp. *paludosa*	-	-	Regionally Rare

55: Desmodium giganticum	-	-	Regionally Rare; Southern Limit
56: Gahnia microstachya	-	-	Regionally Rare; Disjunct; Northern Limit
57: Genoplesium bishopii	-	-	Endemic
58: Gompholobium inconspicuum	-	-	Regionally Rare; Disjunct; Northern Limit
59: Gompholobium pinnatum	-	-	Disjunct; Northern Limit
60: Hibbertia rufa	-	-	Regionally Rare; Northern Limit
61: Kunzea opposita	-	-	Regionally Rare
62: Lasiopetalum ferrugineum var. *cordatum*	-	-	Regionally Rare
63: Leionema dentatum	-	-	Disjunct; Northern Limit
64: Lepidosperma neesii	-	-	Disjunct; Northern Limit
65: Myriophyllum pedunculatum ssp. *pedunculatum*	-	-	Regionally Rare; Northern Limit
66: Nertera granadensis	-	-	Regionally Rare; Disjunct; Northern Limit
67: Patersonia fragilis	-	-	Disjunct
68: Pelargonium inodorum	-	-	Regionally Rare
69: Pomaderris intermedia	-	-	Regionally Rare; Northern Limit
70: Pomaderris ledifolia	-	-	Regionally Rare; Northern Limit
71: Prostanthera howelliae	-	-	Regionally Rare; Disjunct; Northern Limit
72.: Prostanthera saxicola var. *major*	-	-	Regionally Rare; Disjunct
73: Pseudanthus pimeleoides	-	-	Regionally Rare
74: Pterostylis daintreana	-	-	Regionally Rare
75: Pultenaea linophylla	-	-	Regionally Rare
76: Pultenaea petiolaris	-	-	Disjunct
77: Sphaerolobium minus	-	-	Regionally Uncommon
78: Sprengelia incarnata	-	-	Regionally Rare; Northern Limit
79. Telfordia whitei	-	-	Regionally Rare
80: Thelymitra cyanea	-	-	Regionally Rare; Northern Limit
81: Tricostularia pauciflora	-	-	Regionally Rare; Disjunct; Northern Limit

total flora, many of which are endemic to the study area. This number of rare and threatened species is the highest yet recorded for a single reserve within the Bioregion indicating the significance of this conservation area in terms of the conservation of both regionally and continentally important taxa.

Community attributes

Community 3, *Baeckea omissa- Epacris obtusifolia* Bog, has the lowest modelled species density (per 0.1 ha), a low pattern diversity (species turnover) and the component flora has on average low range sizes. In other words this community has comparatively few species but most of them have a generally strong constance between sample sites and a relatively narrow range distribution (Table 1). The taxa of Community 3 are more highly restricted to their habitat, which may not be surprising as this is a community restricted to wetlands at high altitudes, a situation that is poorly-represented across Australia as a whole (Hunter & Bell 2007). The highest turnover was observed within Community 8, *Eucalyptus biturbinata- Lophostemon confertus* forest, which also had a comparatively high species density (Table 1). There is generally poor constancy between sample sites within this assemblage; many new taxa are found in each additional site. The flora of Community 8 had the highest general range sizes. In general the higher turnover was found within Communities 10, 11 and 12. All three of these assemblages share a prominent closed forest component; this is also partially true for Community 8 (Table 1). In contrast the lower pattern diversity scores were found within Communities 1, 2 and 3 all of which share a prominent shrub component. This may imply that closed forest species are locally clumped in distribution and poorly shared between sites, whereas shrubby species have a more general dispersion, and locally will be found within many sites. These proposals would, however, require further investigation.

The flora of Community 11 had the lowest average geographic range sizes in the study area; its component flora was the most restricted in terms of Australian distribution. Restriction may be caused by a number of factors that may occur independently or together within an assemblage. Reasons for such general low broader distribution or restriction may include: the component taxa have poor dispersal abilities, there may be high numbers of endemic taxa, the taxa have restrictive requirements or that many taxa may be refugial. The flora of Community 13 had one of the highest average geographic range sizes. Surprisingly, this same assemblage, when compared with other rock outcrop communities, had one of the lowest range size scores (Hunter 2003a) but a high score for taxa restricted to the habitat (Hunter 2002). Larger geographic range sizes have been linked to increasing available energy (light and heat) inputs and larger available habitats (Kelly 1996; Hunter 2003a; Hunter 2005b). Rock outcrops are very exposed environments and may be considered to have higher levels of available energy than other systems in the study area. The other two assemblages with high average geographic ranges were from Communities 8 and 9 (Table 1). Both these assemblages are generally restricted to lower altitudes and have potentially higher energy inputs from heat. However on this regional scale, differences in the average range sizes are likely to be due to a multitude of factors which would need much more intensive investigation.

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Appendix 1 Vascular plant taxa recorded for plant communities in Gibraltar Range and Washpool National Parks

Nomenclature follows that of Harden (1990–1993) except where recent changes have occurred (PlantNET 2006). * Indicates exotic species. Taxa found within the survey sites are scored according to their presence in each of the 13 communities defined. Some taxa were found in previous surveys or opportunistically and therefore are not assigned to a specific community. Some orchids may be identified in a broad taxonomic sense (*sens. lat.*).

Community 1 = *Eucalyptus olida – Eucalyptus ligustrina – Eucalyptus cameronii*,

Community 2 = *Eucalyptus olida – Eucalyptus pyrocarpa – Eucalyptus planchoniana*,

Community 3 = *Baeckea omissa – Epacris obtusifolia*,

Community 4 = *Eucalyptus campanulata*,

Community 5 = *Eucalyptus oreades – Eucalyptus campanulata*,

Community 6 = *Callicoma serratifolia – Eucalyptus oreades*,

Community 7 = *Leptospermum petersonii – Phebalium squamulosum*,

Community 8 = *Eucalyptus biturbinata – Lophostemon confertus*,

Community 9 = *Eucalyptus carnea – Syncarpia glomulifera – Corymbia gummifera*,

Community10 = *Eucalyptus campanulata – Eucalyptus microcorys*,

Community 11 = *Cryptocarya rigida – Synoum glandulosum*,

Community 12 = *Ceratopetalum apetalum – Caldcluvia paniculosa*

Community 13 = *Kunzea bracteolata – Leptospermum novae-angliae*.

O=opportunistic

	1	2	3	4	5	6	7	8	9	10	11	12	13	O
Acanthaceae														
Brunoniella pumilio									9					
Adiantaceae														
Adiantum aethiopicum				4							11			
Adiantum formosum														O
Adiantum hispidulum	1					6			9					
Adiantum silvaticum														O
Adiantum solensia		2												
Cheilanthes distans														O
Cheilanthes sieberi subsp. *sieberi*	1			4				8	9				13	
Pellaea falcata								8			11	12		
Pellaea nana														O
Agavaceae														O
Cordyline stricta														O
Alangiaceae														
Alangium villosum subsp. *polyosmoides*											11			
Anacardiaceae														
Euroschinus falcata var. *falcata*														O
Annoniaceae														
Rauwenhoffia leichhardtii														O
Anthericaceae														
Arthropodium milleflorum								8						
Dichopogon fimbriatus														O
Laxmannia compacta	1	2			5								13	
Laxmannia gracilis													13	
Thysanotus tuberosus subsp. *tuberosus*	1	2		4										

Apiaceae														
Actinotus gibbonsii														O
Actinotus helianthi														O
Daucus glochidiatus														O
Centella asiatica				4										
Hydrocotyle geraniifolia												12		
Hydrocotyle laxiflora								8						
Hydrocotyle pedicellosa										10		12		
Hydrocotyle peduncularis				4			7			10				
Platysace ericoides	1	2		4				8					13	
Platysace lanceolata														O
Trachymene incisa subsp. *incisa*	1		3	4	5	6		8					13	
Xanthosia pilosa	1	2		4		6		8						
Apocynaceae														
Alyxia ruscifolia					5		7					12		
Parsonsia fulva														O
Parsonsia induplicata										10	11	12		
Parsonsia purpurascens														O
Parsonsia rotata														O
Parsonsia straminea							7							
Parsonsia velutina										10	11			
Araceae														
Alocasia brisbanensis														O
Cordyline rubra														O
Cordyline stricta														O
Gymnostachys anceps				4						10		12		
Araliaceae														
Astrotricha latifolia														O
Cephalaralia cephalobotrys										10	11	12		
Polyscias elegans										10	11			
Polyscias murrayi											11			
Polyscias sambucifolia				4	5					10				
Arecaceae														
Archontophoenix cunninghamiana										10	11			
Linospadix monostachya											11	12		
Asclepiadaceae														
*Asclepias curavassica**														O
*Gomphocarpus fruiticosus**														O
Hoya australis ssp. *australis*														O
Marsdenia flavescens														
Marsdenia jasminoides				4								12		
Marsdenia liisae														
Marsdenia longiloba														
Marsdenia rostrata										10		12		
Tylophora grandiflora														
Tylophora paniculata											11	12		
Tylophora woollsii														
Asphodelaceae														O
Bulbine vagans														
Aspidiaceae														
Arachniodes aristata										10	11			
Aspleniaceae														
Asplenium attenuatum														O
Asplenium australasicum							7			10	11	12		
Asplenium flaccidum subsp. *flaccidum*														O
Asplenium flavellifolium		2		4	5		7	8						
Asplenium polyodon											11			

Asteliaceae														
Cordyline petiolaris											11	12		
Cordyline rubra														O
Cordyline stricta														O
Asteraceae														
Arrhenechthites mixta				4										
*Bidens pilosa**								8						
Brachyscome stuartii						6							13	
Cassinia aureonitens					5									
Cassinia compacta														O
Centratherum punctatum ssp. *australianum*														O
Chrysocephalum apiculatum				4										
*Cirsium vulgare**														O
*Conyza bonariensis**														O
Euchiton gymnocephalus														
Euchiton involucratus														O
Euchiton sphaericus													13	
Glossogyne tannensis									9					
Helichrysum elatum				4						10			13	
Helichrysum rutidolepis														O
Helichrysum scorpioides				4				8	9					
*Hypochaeris radicata**				4		6		8	9				13	
Lagenifera gracilis	1			4				8	9					
Lagenifera stipitata				4										
Olearia elliptica														O
Olearia gravis														O
Olearia microphylla														O
Olearia nernstii				4					9					
Olearia oppositifolia	1			4										
Olearia ramosissima														O
Ozothamnus diosmifolius		2		4									13	
Ozothamnus ferrugineus														O
Podolepis jaceoides														O
Pseudognaphalium luteoalbum														O
Senecio amygdalifolius								8	9					
Senecio bipinnatisectus														O
*Senecio madagascariensis**														O
Senecio minimus														O
Senecio prenanthoides								8						
Senecio quadridentatus								8						
Senecio tenuiflorus														O
Senecio vagus														O
Sigesbeckia orientalis subsp. *orientalis*				4				8						
Solenogyne bellioides													13	
*Sonchus oleraceus**														O
*Taraxacum afficinale**													13	
Telfordia whitei														O
Vernonia cinerea var. *cinerea*				4				8	9					
Athyriaceae														
Diplazium australe														O
Diplazium dilatatum														O
Baueraceae														
Bauera rubioides var. *rubioides*	1		3		5	6								
Bignoniaceae														
Pandorea pandorana				4			7		9		11	12		
Blechnaceae														
Blechnum cartilagineum		2		4	5	6				10	11	12	13	
Blechnum nudum				4								12		

Blechnum patersonii subsp. *queenslandicum*													O
Blechnum wattsii					6						12		
Doodia aspera							8		10				
Doodia caudata													O
Boraginaceae													
Austrocynoglossum latifolium													O
Ehretia acuminata var. *acuminata*													O
Callitrichaceae													
Callitriche muelleri													O
Campanulaceae													
Wahlenbergia littoricola													
Wahlenbergia luteola							8						
Wahlenbergia stricta subsp. *alterna*			4										
Wahlenbergia stricta subsp. *stricta*	1		4										
Casuarinaceae													
Allocasuarina littoralis	1		4									13	
Allocasuarina rigida subsp. *rigida*	1			5	6							13	
Allocasuarina torulosa			4				8	9	10	11			
Celastraceae													
Cassine australis var. *australis*									10		12		
Celastrus subspicata													O
Denhamia celastroides									10				
Denhamia pittosporoides													O
Maytenus bilocularis							8						
Maytenus silvestris													O
Centrolepidaceae	1												
Centrolepis strigosa	1												
Chenopodiaceae													
Einadia polygonoides													O
Clusiaceae													
Hypericum gramineum	1	3	4		6		8	9				13	
Commelinaceae													
Aneilema acuminatum						7							
Commelina cyanea							8						
Pollia crispata													O
Convolvulaceae													
Dichondra repens			4				8						
Crassulaceae													
Crassula sieberiana			4										
Cucurbitaceae													
Zehneria cunninghamii													O
Cunoniaceae													
Aphanopetalum resinosum											12		
Caldcluvia paniculosa			4						10	11	12		
Callicoma serratifolia					6					11	12		
Ceratopetalum apetalum				5	6					11	12		
Schizomeria ovata									10	11	12		
Cupressaceae													
Callitris monticola	1	2		5								13	
Cyatheaceae													
Cyathea australis			4						10	11	12		
Cyathea cooperi													O
Cyathea leichhardtiana													O
Cyperaceae													

Baumea nuda														O
Baumea rubiginosa														O
Bulbostylis densa													13	
Carex appressa				4			7					12		
Carex gaudichaudiana														O
Carex inversa									9					
Caustis flexuosa	1	2			5			8					13	
Cyperus disjunctus										10		12		
Cyperus tetraphyllus														O
Cyperus polystachyos														O
Cyperus sanguinolentus														O
Cyperus sphaeroideus														O
Fimbristylis dichotoma													13	
Gahnia aspera										10				
Gahnia clarkei		2				6								
Gahnia melanocarpa														O
Gahnia microstachya		2												
Gahnia sieberiana		2			5	6				10		12	13	
Gahnia subequiglumis														
Gymnoschoenus sphaerocephalus			3											
Isolepis fluitans														
Lepidosperma elatius		2		4						10				
Lepidosperma filiforme		2		4										
Lepidosperma gunnii		2											13	
Lepidosperma laterale	1	2		4	5	6			9	10			13	
Lepidosperma limicola			3											
Lepidosperma neesii		2											13	
Lepidosperma tortuosum	1	2												
Lepidosperma urophorum		2		4	5				9					
Ptilothrix deusta														O
Schoenus apogon													13	
Schoenus brevifolius								8						
Schoenus ericetorum	1													
Schoenus melanostachys	1	2		4	5	6							13	
Schoenus nitens						6								
Schoenus turbinatus		2	3										13	
Scleria mackaviensis														O
Tricostularia pauciflora														O
Davalliaceae														
Arthropteris beckleri														O
Arthropteris tenella												12		
Davallia solida var. *pyxidata*		2		4			7						13	
Dennstaedtiaceae														
Calochlaena dubia		2		4	5			8		10	11		13	
Histiopteris incisa							7					12		
Hypolepis glandulifera											11			
Pteridium esculentum	1	2		4	5	6		8		10			13	
Dicksoniaceae														
Calochlaena dubia														O
Dicksonia antarctica														O
Dilleniaceae														
Hibbertia acicularis	1													
Hibbertia aspera subsp. *pilosifolia*				4										
Hibbertia dentata				4						10				
Hibbertia empetrifolia subsp. *empetrifolia*		2		4										
Hibbertia obtusifolia				4					9					
Hibbertia rhynocalyx				4										

Hibbertia riparia	1	2		4										
Hibbertia rufa			3			6								
Hibbertia scandens				4			7	8	9	10		12		
Hibbertia serpyllifolia													13	
Hibbertia villosa	1	2											13	
Dioscoreaceae														
Dioscorea transversa														O
Droseraceae														
Drosera auriculata														O
Drosera binata			3			6								
Drosera peltata		2	3										13	
Drosera spatulata		2	3			6							13	
Dryopteridaceae														
Arachnioides aristata														O
Lastreopsis acuminata														O
Lastreopsis decomposita														O
Lastreopsis microsora											11	12		
Polystichum fallax														O
Ebenaceae														
Diospyros australis														O
Diospyros pentamera											11			
Elaeocarpaceae														
Aristotelia australasica														O
Elaeocarpus grandis														O
Elaeocarpus kirtonii														O
Elaeocarpus reticulatus		2		4	5					10				
Sloanea australis												12		
Sloanea woollsii											11	12		
Ericaceae														
Acrotriche aggregata				4					9					
Brachyloma daphnoides subsp. *glabrum*	1		3					8						
Brachyloma saxicola					5	6							13	
Epacris longiflora	1	2			5								13	
Epacris microphylla	1	2	3			6							13	
Epacris obtusifolia			3			6							13	
Epacris pulchella	1													
Leucopogon biflorus														O
Leucopogon juniperinus									9					
Leucopogon lanceolatus var. *lanceolatus*	1	2		4	5		7	8		10			13	
Leucopogon leptospermoides														O
Leucopogon melaleucoides	1	2		4									13	
Leucopogon microphyllus var. *pilibundus*	1												13	
Leucopogon neoanglicus	1	2											13	
Leucopogon sp. aff. *appressus*	1	2												
Leucopogon virgatus		2												
Lissanthe strigosa subsp. *subulata*		2												
Melichrus procumbens	1	2		4									13	
Melichrus urceolatus														O
Monotoca scoparia	1	2		4				8					13	
Sprengelia incarnata				4										
Styphelia triflora	1	2											13	
Styphelia viridis														O
Trochocarpa laurina				4			7		9	10	11			
Escalloniaceae														
Anopterus macleayana											11	12		
Cuttsia viburnea														O
Polyosma cunninghamii												12		

Polyosma cunninghamii											11			
Quintinia sieberi										10	11	12		
Quintinia verdonii														O
Euphorbiaceae														
Amperea xiphoclada var. *xiphoclada*	1	2		4		6		8						
Baloghia inophylla														O
Breynia cernua				4							11			
Claoxylon australe														O
Cleistanthus cunninghamii														O
Drypetes australasica														O
Glochidion ferdinandi														O
Mallotus philippensis														O
Micrantheum hexandrum														O
Omolanthus populifolius											11			
Phyllanthus gunnii														O
Phyllanthus hirtellus		2		4		6							13	
Phyllanthus similis				4										
Phyllanthus virgatus									9					
Poranthera microphylla				4										
Pseudanthus pauciflorus subsp. *pauciflorus*		2											13	
Ricinocarpos speciosus								8	9					
Eupomatiaceae														
Eupomatia laurina											11			
Fabaceae														
Acacia baeuerlenii	1													
Acacia barringtonensis	1	2	3	4									13	
Acacia beadleana													13	
Acacia blakei subsp. *diphylla*									9					
Acacia brunioides subsp. *brunioides*													13	
Acacia brunioides subsp. *granitica*	1													
Acacia cangaiensis				4										
Acacia falciformis	1	2		4						10			13	
Acacia filicifolia	1	2		4		6								
Acacia fimbriata														O
Acacia floribunda				4		6				10		12		
Acacia hispidula		2												
Acacia irrorata				4		6				10		12		
Acacia maidenii														O
Acacia melanoxylon								8						
Acacia mitchellii	1	2												
Acacia myrtifolia				4										
Acacia neriifolia														O
Acacia nova-anglica														O
Acacia obtusifolia	1	2		4		6		8					13	
Acacia rubida														O
Acacia stricta	1					6								
Acacia suaveolens	1	2											13	
Acacia terminalis								8						
Acacia torulosa				4										
Acacia ulicifolia	1	2		4				8					13	
Acacia venulosa	1	2				6							13	
Acacia viscidula													13	
Aotus subglauca var. *filiformis*														O
Aotus subglauca var. *subglauca*	1	2												
Austrosteenisia blackii											11			
Austrosteenisia glabristyla														O
Bossiaea buxifolia														O
Bossiaea neo-anglica	1	2		4				8					13	
Bossiaea prostrata								8						

Bossiaea rhombifolia														O
Bossiaea scortechinii	1	2		4		6								
Chamaecrista nomame var. *nomame*												12		
Crotalaria montana var. *montana*									9					
Daviesia acicularis	1													
Daviesia genistifolia														O
Daviesia latifolia														O
Daviesia nova-anglica														O
Daviesia umbellulata	1	2						8						
Daviesia villifera														
Daviesia wyattiana		2												
Derris involuta														O
Desmodium brachypodum								8						
Desmodium gangeticum				4						10				
Desmodium heterocarpon var. *heterocarpon*														O
Desmodium rhytidophyllum				4				8	9					
Desmodium varians				4				8	9					
Dillwynia phylicoides	1	2		4									13	
Dillwynia rupestris		2			5									
Dillwynia sericea														O
Dillwynia sieberi													13	
Glycine clandestina				4				8	9	10				
Glycine cyrtoloba														O
Glycine microphylla														O
Glycine tabacina								8						
Gompholobium huegelii														O
Gompholobium inconspicuum														O
Gompholobium latifolium	1	2		4				8						
Gompholobium pinnatum														O
Goodia lotifolia subsp. *lotifolia*				4										
Hardenbergia violacea		2		4				8	9					
Hovea heterophylla	1	2												
Hovea lanceolata													13	
Hovea pedunculata	1	2				6							13	
Indigofera australis								8						
Indigofera hirsuta														O
Jacksonia scoparia				4					9					
Kennedia prostrata								8						
Kennedia rubicunda		2		4										
Lespedeza juncea subsp. *sericea*														O
Mirbelia confertiflora	1	2											13	
Mirbelia pungens													13	
Mirbelia rubiifolia	1	2				6							13	
Mirbelia speciosa subsp. *speciosa*	1	2	3										13	
Oxylobium arborescens	1			4										
Phyllota phylicoides	1	2											13	
Podolobium aestivum				4										
Podolobium ilicifolium		2		4										
Pultenaea daphnoides														O
Pultenaea linophylla	1	2		4		6								
Pultenaea petiolaris														O
Pultenaea pycnocephala	1	2												
Pultenaea retusa													13	
Pultenaea tarik	1	2		4	5	6				10			13	
Sphaerolobium minus														O
Sphaerolobium vimineum	1	2	3											
Swainsona brachycarpa														O
Swainsona galegifolia														O
Zornia dyctiocarpa subsp. *dyctiocarpa*									9					

Flacourtiaceae														
Berberidopsis beckleri											11	12		
Streptothamnus moorei										10				
Gentianaceae														
*Centaurium erythraea**														O
Geraniaceae														
Geranium neglectum														O
Geranium retrorsum														O
Geranium solanderi var. *solanderi*				4		6		8						
Pelargonium inodorum														O
Gesneriaceae														
Fieldia australis												12		
Gleicheniaceae														
Gleichenia dicarpa	1	2			5	6								
Gleichenia microphylla														O
Gleichenia rupestris														O
Sticherus lobatus				4		6				10				
Goodeniaceae														
Coopernookia barbata														
Coopernookia chisholmii				4										
Dampiera purpurea	1	2		4					9	10				
Dampiera stricta	1	2	3	4		6		8					13	
Goodenia bellidifolia	1	2	3	4		6		8					13	
Goodenia gracilis														O
Goodenia hederacea subsp. *hederacea*				4					9				13	
Goodenia heterophylla subsp. *eglandulosa*														
Goodenia ovata														O
Goodenia rotundifolia	1	2		4										
Velleia spathulata														
Grammitaceae														
Grammitis billardieri														
Grammitis stenophylla						6								
Haemodoraceae														
Haemodorum planifolium													13	
Haloragaceae														
Gonocarpus micranthus subsp. *ramosissimus*			3			6							13	
Gonocarpus oreophilus						6				10		12	13	
Gonocarpus tetragynus	1	2		4				8						
Gonocarpus teucrioides	1	2		4	5	6		8					13	
Haloragis aspera														O
Haloragis heterophylla														O
Myriophyllum pedunculatum						6								
Hymenophyllaceae														
Cephalomanes caudatum														O
Crepidomanes venosum														O
Hymenophyllum cupressiforme														O
Polyphlebium venosum						6								
Hypoxidaceae														
Hypoxis hygrometrica														O
Icacinaceae														
Citronella moorei												12		
Pennantia cunninghamii														O
Iridaceae														
Patersonia fragilis						6								
Patersonia glabrata	1	2		4				8					13	

Patersonia sericea	1	2		4	5								13	
Juncaceae														
*Juncus bufonius**														O
Juncus continuus														O
Juncus pauciflorus														O
Juncus remotiflorus														O
Juncus subsecundus														O
Luzula flaccida													13	
Lamiaceae														
Ajuga australis														
Plectranthus graveolens									9				13	
Plectranthus parviflorus				4			7	8						
Plectranthus suaveolens														
Prostanthera caerulea	1				5	6				10				
Prostanthera howelliae	1	2		4										
Prostanthera microphylla				4										
Prostanthera ovalifolia														O
Prostanthera nivea									9					
Prostanthera saxicola	1		3										13	
Prostanthera scutellarioides	1					6							13	
Teucrium corymbosum														O
Westringia sericea														O
Lauraceae														
Beilschmiedia elliptica														O
Cassytha filiformis													13	
Cassytha glabella	1	2	3	4		6			9					
Cassytha pubescens	1	2											13	
Cinnamomum oliveri														O
Cinnamomum virens														O
Cryptocarya erythraxylon														O
Cryptocarya foveolata														O
Cryptocarya glaucescens														O
Cryptocarya meissneriana										10	11	12		
Cryptocarya microneura														O
Cryptocarya obovata											11			
Cryptocarya rigida				4						10	11			O
Endiandra crassiflora												12		
Endiandra discolor												12		
Endiandra muelleri														O
Endiandra sieberi										10		12		
Litsea australis														O
Litsea reticulata														O
Neolitsea australiensis											11			
Neolitsea dealbata											11	12		
Lentibulariaceae			3											
Utricularia dichotoma			3											
Liliaceae														
Blandfordia grandiflora			3	4										
Schelhammera undulata														O
Lindsaeaceae														
Lindsaea linearis	1	2	3	4		6							13	
Lindsaea microphylla	1	2		4										
Lobeliaceae														
Isotoma axillaris														O
Lobelia gibbosa														O
Lobelia trigonocaulis				4						10	11	12		
Pratia purpurascens				4				8		10				

Loganiaceae														
Logania albiflora				4										
Logania pusilla	1	2	3	4										
Mitrasacme palludosa														O
Lomandraceae														
Lomandra confertifolia subsp. *pallida*				4						10				
Lomandra elongata														O
Lomandra filiformis subsp. *filiformis*	1	2		4				8	9	10			13	
Lomandra longifolia	1	2		4	5	6	7	8	9	10		12	13	
Lomandra multiflora subsp. *multiflora*	1	2		4				8	9					
Lomandra spicata				4							11	12		
Loranthaceae														
Amyema bifurcatum var. *bifurcatum*														O
Amyema congener								8						
Amylotheca dictyophleba														O
Muellerina celastroides								8						
Luzuriagaceae														
Eustrephus latifolius				4				8		10	11	12		
Geitonoplesium cymosum				4					9	10				
Lycopodiaceae														
Lycopodiella lateralis			3			6								
Lycopodium deuterodensum	1	2												
Lythraceae														
Lythrum hyssopifolia														O
Malvaceae														
Hibiscus splendens									9					
*Sida rhombifolia**														O
Meliaceae														
Dysoxylum fraserianum														O
Dysoxylum rufum														O
Melia azederach var. *azederach*														O
Synoum glandulosum				4						10	11			
Toona ciliata														O
Menispermaceae														
Legnephora moorei											11			
Sarcopetalum harveyanum														O
Stephania japonica var. *discolor*														O
Monimiaceae														
Daphnandra apetala														O
Daphnandra micrantha														
Doryphora sassafras														O
Hedycarya angustifolia														O
Palmeria scandens				4						10	11	12		
Wilkiea austroqueenslandica											11			
Wilkiea huegeliana										10				
Moraceae														
Ficus coronata														
Ficus rubiginosa forma *rubiginosa*									9					
Maclura cochinchinensis														O
Malaisia scandens subsp. *scandens*														O
Streblus brunonianus														
Myoporaceae														O
Eremophila debilis														O
Myrsinaceae														
Embelia australiana														

Myrsine richmondensis										10				
Myrsine variabilis				4										
Myrtaceae														
Acmena smithii							7					12		
Angophora subvelutina														O
Archirhodomyrtus beckleri				4					9	10				
Backhousia myrtifolia														O
Baeckea gunniana														O
Baeckea omissa	1		3			6							13	
Callistemon comboynensis													13	
Callistemon linearis														O
Callistemon pallidus	1	2				6							13	
Callistemon pityoides														O
Callistemon salignus														O
Callistemon sieberi						6								
Callistemon sp. aff. *montanus*		2												
Callistemon viminalis						6								
Calytrix tetragona		2											13	
Corymbia citriodora subsp. *variegata*														O
Corymbia gummifera				4					9					
Corymbia intermedia														O
Eucalyptus acaciiformis	1												13	
Eucalyptus acmenoides								8						
Eucalyptus biturbinata								8	9					
Eucalyptus brunnea				4										
Eucalyptus caliginosa	1	2		4						10				
Eucalyptus cameronii	1	2		4				8					13	
Eucalyptus campanulata		2		4	5			8		10	11			
Eucalyptus carnea								8	9	10				
Eucalyptus codonocarpa		2											13	
Eucalyptus crebra														O
Eucalyptus dalrympleana subsp. *heptantha*	1													
Eucalytpus dissita														O
Eucalyptus fibrosa								8						
Eucalyptus laevopinea														O
Eucalyptus ligustrina	1												13	
Eucalyptus microcorys				4				8	9	10	11	12		
Eucalyptus notabilis				4									13	
Eucalyptus obliqua				4						10		12		
Eucalyptus olida	1	2		4										
Eucalyptus oreades	1	2		4	5	6								
Eucalyptus planchoniana		2						8	9					
Eucalyptus pyrocarpa	1	2						8	9					
Eucalyptus radiata subsp. *sejuncta*	1												13	
Eucalyptus saligna				4						10	11	12		
Eucalyptus siderophloia														O
Eucalyptus subcaerulea									9					
Eucalyptus tereticornis														O
Eucalyptus tindaliae														O
Eucalyptus williamsiana	1	2												O
Kunzea bracteolata	1	2			5								13	
Kunzea ericoides														O
Kunzea opposita														O
Leptospermum arachnoides	1		3										13	O
Leptospermum brachyandrum													13	
Leptospermum brevipes													13	
Leptospermum microcarpum	1													
Leptospermum minutifolium	1												13	
Leptospermum novae-angliae	1				5								13	O

Leptospermum petersonii subsp. *petersonii*		2					7		9					O
Leptospermum polygalifolium subsp. *cismontanum*	1	2		4		6			9					
Leptospermum polygalifolium subsp. *montanum*		2												
Leptospermum polygalifolium subsp. *transmontanum*														O
Leptospermum trinervium	1	2		4	5	6		8					13	
Leptospermum variabile														O
Lophostemon confertus				4				8	9	10	11			
Melaleuca tortifolia														O
Micromyrtus sessilis														O
Rhodamnia rubescens											11	12		
Syncarpia glomulifera subsp. *glomulifera*									9	10				
Syzygium australe														O
Syzygium corynanthum														O
Syzygium crebrinerve														O
Syzygium francisii														O
Syzygium luehmannii														O
Syzygium oleosum														O
Tristaniopsis laurina														O
Oleaceae														
Notelaea johnsonii										10				
Notelaea linearis	1		3	4										
Notelaea longifolia forma *intermedia*				4			7							
Notelaea sp. A										10		12		
Notelaea venosa														O
Ophioglossaceae														
Botrychium australe														O
Osmundaceae														
Todea barbara														O
Orchidaceae														
Acianthus caudatus														O
Acianthus exsertus				4										O
Acianthus fornicatus		2		4										
Bulbophyllum bracteatum														O
Bulbophyllum elisae														O
Caladenia alata														O
Caladenia carnea														O
Caladenia catenata														O
Caladenia picta														O
Calanthe triplicata														O
Caleana major														O
Caleana minor														O
Calochilus campestris				4										
Calochilus grandiflorus														O
Calochilus paludosus														O
Chiloglottis diphylla				4									13	
Chiloglottis sphyrnoides														O
Chiloglottis sylvestris	1					6								
Corybas aconitiflorus		2		4		6			9	10				
Corybas fimbriatus														O
Cryptostylis erecta														O
Cryptostylis hunterana	1													
Cryptostylis subulata	1	2		4									13	
Cymbidium canaliculatum														O
Cymbidium suave														O
Dendrobium aemulum														O
Dipodium punctatum														O

Dipodium variegatum				4										
Diuris maculata														O
Diuris punctata														O
Diuris sulphurea														O
Dockrillia bowmanii														O
Dockrillia linguiniformis														O
Dockrillia pugioniformis				4		6						12	13	
Dockrillia schoenina														O
Dockrillia teretifolia														O
Eriochilus autumnalis														O
Eriochilus cucullatus				4										
Gastrodia sesamoides														O
Genoplesium bishopii														O
Genoplesium fimbriatum													13	
Glossodia minor														O
Liparis coelogynoides														O
Liparis reflexa														O
Liparis swenssonii														O
Microtis unifolia														O
Orthoceras strictum			3											
Plectorrhiza tridentale														O
Prasophyllum brevilabre													13	
Prasophyllum flavum														O
Pterostylis abrupta														O
Pterostylis baptistii														O
Pterostylis curta														O
Pterostylis daintreana														O
Pterostylis longifolia				4									13	
Pterostylis nutans				4					9					
Pterostylis parviflora													13	
Pterostylis pedunculata														O
Sarcochilus ceciliae														O
Sarcochilus falcatus														O
Sarcochilus spathulatus							7							
Spiranthes sinensis	1													
Thelychiton kingianus														O
Thelychiton speciosus														O
Thelychiton tarberi														O
Thelymitra cyanea														O
Thelymitra ixioides var. *ixioides*														O
Oxalidaceae														
Oxalis chnoodes														O
Oxalis corniculata														O
Oxalis exilis				4				8		10				
Passifloraceae														
Passiflora edulis														O
Passiflora herbertiana														O
Peperomiaceae														
Peperomia tetraphylla														O
Phormiaceae														
Dianella caerulea var. *assera*														O
Dianella caerulea var. *caerulea*	1	2		4	5		7	8	9	10	11	12	13	
Dianella caerulea var. *producta*	1	2		4	5							12		
Dianella revoluta var. *revoluta*	1												13	
Dianella tasmanica													13	
Stypandra glauca													13	
Thelionema caespitosum			3										13	
Thelionema grande			3		5									

Phytolaccaceae														
*Phytolacca octandra**													13	
Piperaceae														
Piper novae-hollandiae										10	11			
Pittosporaceae														
Billardiera scandens var. *scandens*	1	2		4	5	6				10				
Bursaria spinosa subsp. *obovata*				4					9					
Hymenophyllum flavum														O
Pittosporum multiflorum											11	12		
Pittosporum revolutum														O
Pittosporum undulatum				4						10	11			
Rhytidosporum procumbens	1		3											
Plantaginaceae														
Plantago debilis				4										
Poaceae														
Amphipogon strictus			3										13	
Aristida queenslandica									9					
Aristida ramosa		2											13	
Aristida vagans				4										
Austrodanthonia bipartita														O
Austrodanthonia monticola														O
Austrodanthonia richardsonii													13	
Austrostipa bigeniculata													13	
Austrostipa pubescens	1	2												
Austrostipa ramosissima														O
Austrostipa rudis subsp. *nervosa*														O
Austrostipa scabra													13	
Austrostipa sp. A.	1													
*Axonopus affinis**			3			6								
Bothriochloa macra														O
Capillipedium parviflorum														O
Capillipedium spicigerum				4				8						
Cleistochloa rigida													13	
Cymbopogon refractus								8	9					
Deyeuxia mckiei														O
Deyeuxia parviseta									9					
Dichelachne micrantha								8						
Digitaria breviglumis													13	
Digitaria diffusa														O
Digitaria parviflora									9					
Echinopogon caespitosus var. *caespitosus*								8						
Enneapogon nigricans														O
Entolasia stricta	1	2	3	4	5	6		8	9	10			13	
Eragrostis brownii								8	9					
Eragrostis elongata														O
Eragrostis leptostachya		2												
*Eragrostis tenuifolia**														O
Imperata cylindrica var. *major*	1	2		4				8	9					
Joycea pallida														O
Lachnagrostis aemula										10				
Lachnagrostis filiformis														O
Microlaena stipoides var. *stipoides*		2		4				8						
Oplismenus aemulus				4			7	8	9	10				
Oplismenus imbecillis				4			7	8	9	10	11			
Panicum paludosum			3											
Panicum simile				4		6		8	9			12		
Paspalidium constrictum													13	
*Pennisetum clandestinum**														O

Poa queenslandica				4										
Poa sieberiana	1	2		4		6		8	9				13	
*Setaria pumila**														O
Sorghum leiocladum				4										
Sporobolus creber														O
Sporobolus diander														O
Tetrarrhena juncea	1	2	3	4		6		8					13	
Themeda triandra				4				8					13	
Tripogon loliiformis													13	
Urochloa foliolosa													O	
Polygalaceae														
Comesperma defoliatum			3											
Comesperma ericinum	1	2		4	5								13	
Comesperma retusum														O
Comesperma sphaerocarpum														O
Muehlenbeckia gracillima				4										
Muehlenbeckia rhyticarya														O
Persicaria decipiens														O
Polygala japonica								8						
Polypodiaceae														
Dictymia brownii														O
Microsorum scandens											11	12		
Platycerium bifurcatum subsp. *bifurcatum*		2		4							11		13	
Platycerium superbum														O
Pyrrosia confluens														O
Pyrrosia rupestris				4			7					12	13	
Portulacaceae														
Calandrinia eremaea													13	
Calandrinia pickeringii														O
Proteaceae														
Banksia cunninghamii subsp. A	1	2		4										
Banksia integrifolia subsp. *integrifolia*				4	5		7			10				
Banksia marginata														O
Banksia spinulosa var. *collina*	1		3			6		8					13	
Banksia spinulosa var. *neoanglica*														O
Conospermum burgessiorum	1	2												
Conospermum taxifolium														O
Grevillea acanthifolia subsp. *stenomera*	1		3											
Grevillea acerata	1	2				6							13	
Grevillea mollis				4					9					
Grevillea mucronulata													13	
Grevillea rhizomatosa	1	2		4										
Hakea eriantha	1	2		4										
Hakea laevipes subsp. *graniticola*	1	2	3			6							13	
Hakea macrorrhyncha		2											13	
Hakea salicifolia		2		4	5	6				10				
Helicia glabriflora														O
Isopogon petiolaris	1		3										13	
Lomatia fraseri				4										
Lomatia silaifolia	1	2		4	5	6		8	9	10				
Orites excelsa					5				9		11	12		
Persoonia adenantha				4					9	10				
Persoonia cornifolia													13	
Persoonia media														O
Persoonia oleoides		2		4				8						
Persoonia rufa	1	2		4	5			8					13	
Persoonia sericea				4				8						

Petrophile canescens	1	2		4				8					13	
Stenocarpus salignus														O
Telopea aspera	1	2		4										
Psilotaceae														
Psilotum nudum														O
Tmesipteris ovata														O
Pteridaceae														
Pteris tremula												12		
Pteris umbrosa											11			
Ranunculaceae														
Clematis aristata				4							11			
Clematis glycinoides				4							11	12		
Ranunculus lappaceus						6								
Restionaceae														
Baloskion fimbriatum	1		3			6								
Baloskion stenocoleum														O
Empodisma minus														O
Lepyrodia anarthria			3										13	
Lepyrodia leptocaulis													13	
Lepyrodia scariosa	1	2	3			6							13	
Rhamnaceae														
Alphitonia excelsa														O
Cryptandra lanosiflora													13	
Cryptandra scortechinii	1													
Emmenosperma alphitonioides														O
Pomaderris andromedifolia				4									13	
Pomaderris intermedia														O
Pomaderris lanigera				4										
Pomaderris ledifolia														O
Pomaderris nitidula				4										
Ripogonaceae														
Ripogonum album	1													
Ripogonum fawcettianum														O
Rosaceae														
Rubus moluccanus var. *moluccanus*														O
Rubus moluccanus var. *trilobus*							7					12		
Rubus moorei														O
Rubus nebulosus						6	7			10	11			
Rubus parvifolius				4				8						
Rubus rosifolius														O
Rubiaceae														
Galium binifolium				4										
Galium propinquum				4			7			10				
Morinda jasminoides										10	11	12		
Opercularia aspera														O
Opercularia hispida	1	2		4		6		8	9					
Pomax umbellata		2		4				8	9	10	11		13	
Psychotria daphnoides										10				
Psychotria loniceroides				4							11			
Spermacoce brachystema									9					
Rutaceae														
Acradenia euodiiformis											11	12		
Acronychia laevis														O
Acronychia oblongifolia														O
Acronychia pubescens														O
Acronychia suberosa														O
Asterolasia correifolia														O

Boronia algida	1	2		4									13	
Boronia anethifolia					5								13	
Boronia angusepala	1				5									
Boronia bipinnata														O
Boronia microphylla	1	2		4									13	
Boronia parviflora			3											
Boronia polygalifolia			3											
Boronia rubiginosa														O
Correa lawrenciana var. *glandulifera*														O
Correa reflexa var. *reflexa*				4										
Eriostemon australasius		2											13	
Geijera latifolia														O
Leionema ambiens														O
Leionema dentatum					5								13	
Medicosma cunninghamii														O
Melicope hayesii														O
Melicope micrococca												12		
Phebalium squamulosum							7					12	13	
Phebalium woombye														
Sarcomelicope simplicifolia														O
Zieria arborescens subsp. *arborescens*												12		
Zieria fraseri subsp. *compacta*													13	
Zieria furfuracea														O
Zieria smithii subsp. *smithii*				4		6	7			10				
Sambucaceae														
Sambucus australasica														O
Santalaceae														
Choretrum candollei	1	2		4										
Choretrum sp. A													13	
Exocarpos strictus	1												13	
Leptomeria acida														O
Leptomeria aphylla														O
Leptomeria drupacea														O
Santalum obtusifolium														O
Sapindaceae														
Alectryon subcinereus														O
Diploglottis australis														O
Diploglottis cunninghamii											11	12		
Dodonaea megazyga														O
Dodonaea serratifolia				4										
Dodonaea triquetra		2							9					
Dodonaea viscosa														O
Guioa semiglauca											11			
Schizaeaceae														
Schizaea bifida	1	2		4				8					13	
Schizaea dichotoma														O
Scrophulariaceae														
Euphrasia collina subsp. *paludosa*														O
Veronica calycina								8						
Veronica notabilis														O
Veronica plebeia				4										
Smilacaceae														
Smilax australis	1			4	5					10	11	12	13	
Smilax glyciphylla		2		4	5	6				10	11		13	
Solanaceae														
Duboisia myoporoides				4						10				
Solanum aviculare														O

Solanum campanulatum				4						10				
*Solanum mauritianum**				4										
Solanum nemophilum				4						10				
Solanum neoanglicum														O
Solanum nobile														O
Solanum opacum														O
Solanum prinophyllum														O
Solanum pungetium														O
Solanum stelligerum														O
Stackhousiaceae														
Stackhousia viminea	1			4				8						
Sterculiaceae														
Brachychiton acerifolius														O
Kerandrenia corollata var. *denticulata*														O
Lasiopetalum ferrugineum var. *cordatum*		2												
Rulingia dasyphylla														O
Rulingia salviifolia														O
Seringia arborescens														O
Stylidiaceae														
Stylidium graminifolium				4										
Stylidium laricifolium				4									13	
Surianaceae														
Guilfoylia monostylis														O
Symplocaceae														
Symplocos stawellii														O
Symplocos thwaitesii														O
Thelypteridaceae														
Christella dentata														O
Thymelaeaceae														
Pimelea latifolia														O
Pimelea ligustrina														O
Pimelea linifolia	1	2		4					9				13	
Pimelea neo-anglica														O
Tremandraceae														
Tetratheca thymifolia	1													
Trimeniaceae														
Trimenia moorei											11			
Ulmaceae														
Aphananthe philippinensis														O
Urticaceae														
Dendrocnide excelsa														O
Dendrocnide photinophylla														O
Elatostema stipitatum														O
Urtica incisa														O
Verbenaceae														
Clerodendrum tomentosum				4				8		10				
Gmelina leichhardtii										10				
*Lantana camara**										10				
*Verbena rigida**														O
Violaceae														
Hybanthus enneaspermus									9					
Hybanthus monopetalus			3	4										
Hybanthus vernonii subsp. *vernonii*														O
Viola betonicifolia	1			4		6		8						
Viola hederacea		2		4				8		10		12		

Vitaceae														
Cayratia clematidea														O
Cayratia eurynema														O
Cissus antarctica	1			4							11			
Cissus hypoglauca				4			7	8		10	11	12		
Cissus sterculifolia														O
Tetrastigma nitens														O
Vitteriaceae														
Vittaria elongata														O
Winteraceae														
Tasmannia insipida							7				11	12		
Xanthorrhoeaceae														
Xanthorrhoea acaulis													13	
Xanthorrhoea australis														O
Xanthorrhoea glauca subsp. *angustifolia*				4				8	9	10			13	
Xanthorrhoea johnsonii	1	2		4										
Xanthorrhoea latifolia		2						8						
Xyridaceae														
Xyris gracilis														O
Xyris operculata			3											
Zingiberaceae														
Alpinia caerulea														O

Montane lakes (lagoons) of the New England Tablelands Bioregion

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Abstract: The vegetation of montane lagoons of the New England Tablelands Bioregion, New South Wales is examined using flexible UPGMA analysis of frequency scores on all vascular plant taxa, charophytes and one liverworts. Seven communities are described-

1. *Hydrocotyle tripartita – Isotoma fluviatilis – Ranunculus inundatus – Lilaeopsis polyantha* herbfield
2. *Eleocharis sphacelata – Potamogeton tricarinatus* sedgeland
3. *Eleocharis sphacelata – Utricularia australis – Isolepis fluitans,* herbfield
4. *Utricularia australis – Nitella sonderi* herbfield
5. *Eleocharis sphacelata – Utricularia australis – Ricciocarpus natans* sedgeland
6. *Carex gaudichaudiana – Holcus lanatus – Stellaria angustifolia* sedgeland
7. *Cyperus sphaeroides – Eleocharis gracilis – Schoenus apogon – Carex gaudichaudiana* sedgeland.

58 lagoons were located and identified, only 28% of which are considered to be intact and in good condition. Two threatened species (*Aldovandra vesiculosa* and *Arthaxon hispidus)* and three RoTAP-listed taxa were encountered during the survey.

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Introduction

Temporary wetlands are far more common and widely distributed in Australia than are permanent lakes and swamps (Paijmans 1985); in the New England Bioregion, on the New South Wales Northern Tablelands, shallow lentic wetlands are a feature of the flat terrain derived from Tertiary basalt flows. More than 70% of these montane wetlands have been drained or dammed (Brock *et al*. 1999; Keith 2004).

Keith (2004) refers to the intermittent and semi-permanent wetlands found on deflation hollows of the NSW Northern Tablelands and the Southern Tablelands Monaro region as montane lakes; Jacobs & Brock (1993) describe these wetlands as ephemeral lakes and swamps. However Paijmans *et al.* (1985) restricts lakes to those water-bodies greater than 1 m deep when full, a definition that would exclude all but two of the wetlands on the New England Tablelands Bioregion. Timms (1992) discusses the pitfalls of attempting to define lakes in Australia where many lakes are ephemeral, and in his study excluded small water bodies (ponds; <1 ha) and those where vegetation dominates the water surface (swamps). We have reservations about using the term lake for these New England Tablelands wetlands, since all are dominated by emergent macrophytes, most are shallow, and a few are less than 1 ha. It is symptomatic of this confusion over terminology that sees Benson & Jacobs (1994) describe these systems on the Monaro as lakes, while describing all vegetation communities present as marshes. Globally these systems would probably best be described as semi-permanent or ephemeral marshes (Usback & James 1993). Like some of the geomorphological literature (Walker 1976; Haworth et al. 1999) and local custom, we will refer to these wetlands as lagoons (Usback & James 1993; Bell & Clarke 2004; Benson & Ashby 2000).

The Northern Tablelands lagoons are shallow (mostly < 1.5 m deep) upland wetlands and ponds, typically located in saucer-shaped areas of negative relief with closed or semi-closed drainage, on flat or gently undulating landscapes associated with Tertiary basalt flows (Walker 1977). A distinguishing feature are their well-defined and apparently wave-cut banks that contrast with sandy lunettes on their downwind shores, both features indicating that they formed under climatic conditions different from the present.

Lagoons differ from other regional wetlands in morphology and location. Most are oval-shaped, often with distinct rocky margins, though with considerable recent silt accumulation on their edges. They occur above 900 m, close to the top of the Great Divide or to adjacent leading ridges, and inland of the 1000 mm rainfall isohyet. They are not found in the wettest areas of the eastern 'falls country', but in more inland areas prone to cycles of wetting and drying, where weathering by watertable fluctuation is more intense. Retention of water in the closed basins is facilitated by drainage impediment caused by the accumulation of the secondary products of weathering, such as stiff clays and the duricrusts ferricrete and silcrete. These secondary products are most commonly associated with basalt weathering but may occasionally form from different rock types under similar environmental conditions, probably that of marked seasonal variation in watertables and subsequent precipitation of duricrust minerals.

Lagoons receive water from their relatively small catchments by combinations of hydrological processes; some are mainly stream-fed, some spring-fed and some fed by overland flow. Most lagoons were probably initiated by return-flow sapping at the base of basalt rises, and some have marginal peatlands that may retain moisture when the central basin is dry. Though largely closed systems, water may spill into the adjoining major river catchments, the Clarence, Macleay or Gwydir, in extreme floods.

Similar lagoons are found in low relief tableland areas along the Great Divide e.g. the Monaro (Pillans 1987; Benson & Jacobs 1994). Although most often associated with basalt lithologies, they are not volcanic in origin. Apart from obvious differences in morphology to volcanic maars, the superficial nature of the drainage-divide lagoons was demonstrated by Coenraads (1989) who drilled through the basement of four Glen Innes lagoons to the underlying country rock.

Some lagoons have either sand dunes or clay-rich mounds on their eastern (lee) side called 'lunettes' (because of their typical wind-formed crescent shape), and probably products of deflation or wave action formed under different climatic conditions during the glacial cycle of the last 2 million years (Pillans 1987). Unlike most lakes, their basins tend to be renewed by deflation (wind erosion) over periods of tens of thousands of years, and as their catchments are small, they are rarely completely infilled. Lagoon sediments are rarely more than several metres deep, and radiocarbon dating of the peat fraction indicates that the present cycle of sedimentation commenced approximately 15 000 years ago, as climate became wetter and warmer after the last Glacial Maximum (Haworth 1994; Haworth et al. 1999).

Since European settlement the hydrology of the Northern Tableland lagoons has been extensively altered by agricultural practices such as draining, impoundment, excavation and grazing (Walker 1977; Brock et al. 1997; Benson & Ashby 2000). A preliminary inventory using map and air photo analysis (Walker 1977) identified 29 lagoons in New England but since Walker's 1977 study it has become obvious that there are more lagoons in this region, and that the majority are highly modified, and the vegetation communities in them are under threat. Vegetation typical of these lagoons is included in the Endangered Ecological Communities *Upland Wetlands of the Drainage Divide of the New England Tableland Bioregion* (listed under the NSW *Threatened Species Conservation Act 1995*) and *Upland wetlands of the New England Tablelands and the Monaro Plateau* (listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*).

Management and conservation initiatives require an up-to-date understanding of the extent and condition of these lagoons. Past descriptions of vegetation have either been limited to a single site (Millington 1949), or have focussed on a sub-regional scale i.e. lagoons of the Guyra 1:100 000 Map Sheet (Benson & Ashby 2000). Other investigators have dealt with the ecology of individual taxa or groups of taxa, e.g. *Myriophyllum variifolium* (Brock 1991), the family Characeae (Casanova 1993; Casanova & Brock 1999), the relationships between *Glyceria australis* and *Juncus articulatus* (Smith & Brock 1996), or co-existence within the genus *Eleocharis* (Bell & Clarke 2004). Other work has focussed on seedbanks (Brock 1998); a long-term vegetation survey of six lagoons revealed habitat partitioning (zonation) in both standing vegetation and soil seedbank (Bell 2000).

Some temporary wetlands species display considerable morphological plasticity with different architectural forms, one for growing in the water column and another for surviving on damp mud (Brock 1991). These species are termed amphibious responders by Brock & Casanova (1997), who allocated Northern Tablelands wetlands species into three broad functional groups based on their establishment characteristics.

It is our intention to 1) investigate the location, extent and integrity of lagoons on the Northern Tablelands Bioregion and provide a current inventory; and 2) describe lagoon vegetation community patterns and their compositional and distributional gradients. This study forms part of a broader investigation on montane wetlands systems of the Northern Tablelands (Hunter & Bell 2007).

Methods

The vegetation of six of the least disturbed lagoons (Llangothlin, Little Llangothlin, Pinch, Billybung, Kolora and Wyanbah Lagoons) was sampled in January 1998. The lagoons had, at that time, been experiencing relatively high rainfall for the previous three years and all but Wyanbah held water. The southern and northern ends of the 250 hectare Llangothlin Lagoon and the grazed and un-grazed sides of Billybung Lagoon were considered as separate sites; 3 transects per site (24 transects total) were placed perpendicular to the shoreline from the approximate high water mark to a few metres into the central *Eleocharis sphacelata* stands. The lower edge of the *Carex gaudichaudiana* stands, where they occurred, were deemed to be the high water mark; if *Carex* was absent, the grass *Hemarthria uncinata* marked the upper end of the transect.

The presence/absence of all vascular plant species, charophytes and the large floating liverwort *Ricciocarpus natans* was recorded in contiguous 0.5 m x 0.5 m (¼ m^2)

quadrats along the whole length of each transect. Both charophytes and *Ricciocarpus natans* are often common to dominant elements of these communities (Casanova 1993). After sampling, vegetation was stratified along transects into two to four visually distinct bands per site. Multivariate analysis data consisted of frequency scores for each species in plots consisting of six contiguous quadrats (total area 3.00 x 0.5 m) from a random position within each band (68 plots in total). Frequency scores ranged from one (present in one quadrat in the plot) to six (present in all quadrats). Nomenclature follows that of Harden (1990–1993) except where recent changes have occurred (PlantNET 2006). Species life history types (submerged, floating submerged, floating-leaved, emergent and terrestrial) were allocated to each species. Terrestrial species were those not normally found in intact wetlands in either their dry or flooded states.

The depth profile of each transect was measured at 1 m intervals using a datum point at the high water end of the first transect and measuring depths with a dumpy level. Transects varied in length from 62 m (Billybung un-grazed) to 362 m (Little Llangothlin). Water depth at the deepest point on transects varied from zero at Wyanbah to 1.39 m at Little Llangothlin Lagoon.

All lagoons were visited from 1989 to 1992 and in 2006 (first author, 20 sites only) and opportunistically on other occasions. Landholders were asked about the history of each lagoon, particularly on the history of hydrological changes such as drainage and impoundment. Each site was traversed and vegetation, water depth and hydrological changes noted. In 2006 a number of newly identified sites were visited.

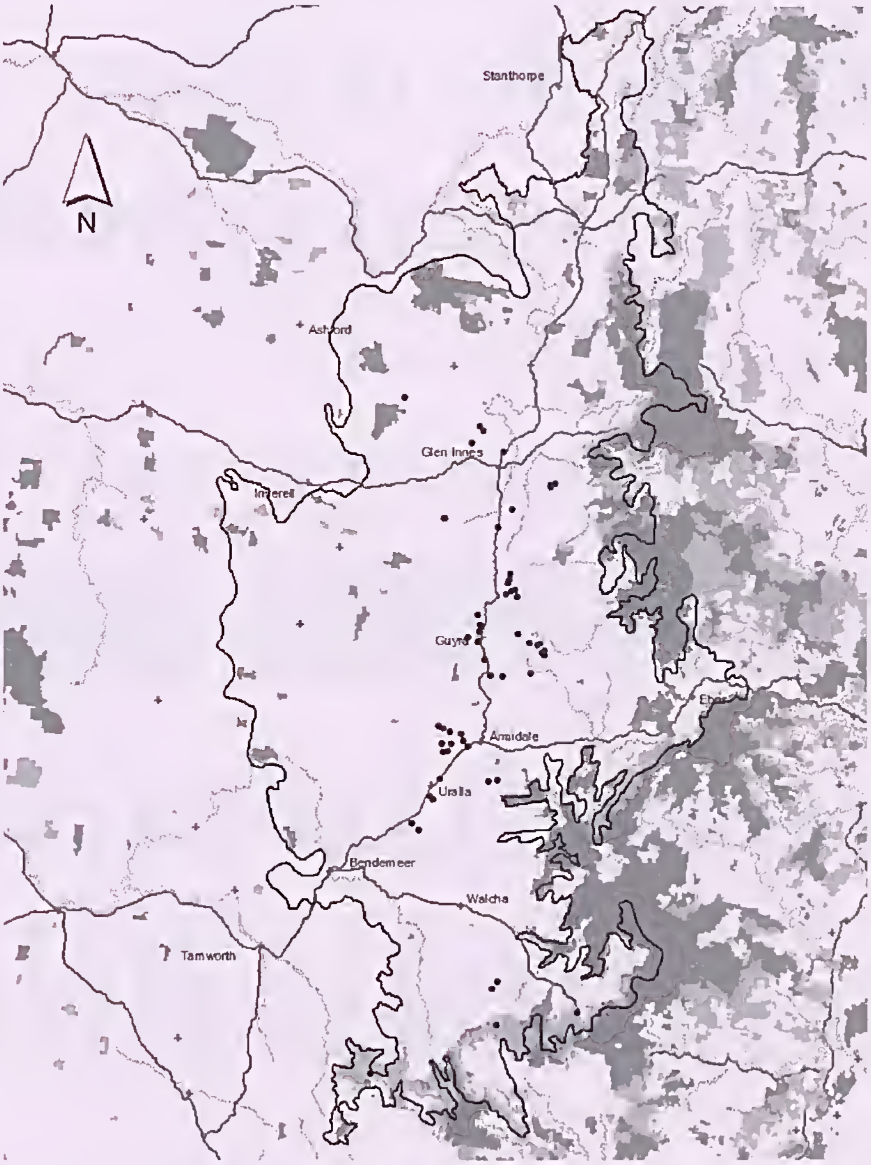

Fig. 1. Location and extent of lagoons of the New England Tablelands Bioregion. Circles are lagoon locations, dark grey are National Park estate and light grey is State Forest estate, dark line is the boundary for the New England Tablelands Bioregion.

Table 1. Distribution, description and condition of montane lagoons on the Northern Tablelands Bioregion of NSW.

Lagoon Group	Lagoon	Tenure	Lat/Long	Altitude (m)	Basin area (ha)	Parent material	Hydrological disturbance	Notes
	Kings Plains	Private	29°38′02″S 151°26′40″E	930	2	Basalt		Apparently intact, very shallow.
Glen Innes	Clarevaulx	Private	29°37′06″S 151°40′30″E	1010	140	Basalt	Drained	Multiple drains.
	Dunvegan	Private	29°37′55″S 151°41′09″E	1013	14	Basalt	Drained	Pipe in low wall to manipulate drainage. Western side ploughed and sown to fescue.
	Reddestone	TSR/Private	29°40′03″S 151°38′49″E	1034	30	Basalt	Drained	Much altered. Drain through centre plus 2 dams interrupt drain. V-shaped wall further north across basin. Original area difficult to determine.
	Treriffiths	Private	29°41′33″S 151°45′00″E	1081	2	Basalt	Small dam at margin	Essentially intact.
	John Ryall	Private	29°47′05″S 151°55′13″E	1186	7	Basalt		Essentially intact. Low wall at northern end appears to have no impact on hydrology.
	Glen Athol North	Private	29°47′17″S 151°54′19″E	1185	4	Basalt	Slight impoundment	Divided by a raised mound (& ditch) supporting east/west fence.
	Glen Athol West	Private	29°47′41″S 151°54′00″E	1185	5	Basalt	Drained	Three wide shallow drains, road-works across north-east corner.
	Blair Hill	Private	29°51′32″S 151°46′40″E	1269	4	Basalt		Intact, shallow but badly trampled by cattle.
	Barleyfield-Glencoe	Crown Land	29°54′32″S 151°43′50″E	1144	10	Basalt		Intact.
	Novar	Private	29°52′53″S 151°33′29″E	1345	<1	Basalt	Slight	Very shallow. Small ditch dug in basin with low bank.
	West Novar	Private	29°52′47″S 151°33′08″E	1342	<0.5	Basalt	Impounded	Very shallow. Edge of wetland excavated to form high dam wall.
Llangothlin	North Llangothlin	Private	30°02′29″S 151°46′08″E	1362	7	Basalt/ granite	Impounded	No wetland vegetation.
	Llangothlin	Private	30°03′30″S 151°45′54″E	1354	410	Basalt/ granite		Outlet lowered previously then restored.
	South Llangothlin	Private	30°04′02″S 151°45′45″E	1368	3	Basalt		Intact, very shallow.
	Little Llangothlin	Nature Reserve	30°05′11″S 151°47′00″E	1355	100	Basalt/ granite		Outlet lowered previously then restored in 199?
	Billy Bung	Private/ Nature Reserve	30°05′26″S 151°46′24″E	1363	25	Basalt		Essentially intact. Never drained.
	Tubbamurra	Private	30°06′01″S 151°45′17″E	1355	4	Basalt	Drained, dam in lagoon bed	Drained at outlet, some excavation for road-fill.
	Abbey Green	Private	30°06′17″S 151°47′29″E	1351	11	Basalt/ granite	Drained	Outlet lowered 60 cm, older shallow drainage system.
	Kyoma	Private	30°07′45″S 151°43′05″E	1348	3	Granite-silcrete		Very shallow. Slightly impounded by road. Silerete and sitereted conglomerate boulders on lagoon bed.

Guyra	Everetts Flat	Private	30°09′20″S 151°39′35″E	1312	27	Basalt/ granite	Drained	2m deep drain to south, partly cultivated.
	Little Waterview	Private	30°11′00″S 151°40′01″E	1318	5	Basalt	Drained	Central drain.
	Waterview	Private	30°11′13″S 151°40′22″E	1317	11	Basalt	Impounded	Used for abattoir waste water for many years.
	Elmwood	Private	30°12′10″S 151°39′55″E	1320	16	Basalt		Cultivated.
	Sabot	Private	30°13′17″E 151°37′40″S	1325	5	Basalt		Intact.
	Mother of Ducks	Private/ DEC	30°14′00″S 151°39′30″E	1315	430	Basalt	Drained	Outlet lowered 2m, partly enclosed by dyke & moat.
	Pinch (Dittons, Black Mountain, Little)	Private	30°17′05″S 151°40′56″E	1335	43	Basalt	Drained	System of marginal drains feeding into lowered (now approx 80 cm) outlet, but impact on vegetation slight.
Brockley	Bald Blair	Private	30°12′45″S 151°47′30″E	1277	25	Basalt	Impounded in 1960s	Loss of all aquatic vegetation.
	Kolara	Private	30°14′13″S 151°49′46″E	1330	8	Basalt		Essentially intact, drained previously but restored, small dam near outlet.
	Edenglen (upper)	Private	30°14′40″S 151°51′26″E	1312	8	Basalt	Drained	Deep central drain, outlet lowered.
	East Edenglen (lower)	Private	30°14′33″S 151°51′48″E	1306	6	Basalt	Drained	Drainage system with central drain, outlet lowered at least 60 cm.
	Brockley Swamp	Private	30°16′20″S 151°52′40″E	1282	20	Basalt	Drained	Central drain excavated 1980s, outlet now on opposite side to natural outlet. Drain deepened in 1994.
	Little Brockley	Private	30°16′00″S 151°52′10″E	1300	2	Basalt	Drained	Site difficult to identify because of drainage.
	East Brockley	Private	30°15′45″S 151°52′40″E	1290	2	Basalt	Drained	Site difficult to identify, apparently covered by an airstrip.
	Loch Abbra	Private	30°19′27″S 151°49′51″E	1306	8	Basalt	Dam wall across northern end	Essentially intact, dam wall not effective.
	Anthony's	Private	30°20′05″E 151°44′20″S	1335	1	Basalt	Impounded	Loss of all aquatic vegetation.
	Copnor	Private	30°19′45″S 151°41′50″E	1330	1	Basalt		Apparently intact.
Armidale	Primrose Hill (Hillwood)	Private	30°28′19″S 151°31′32″E	1075	6	Greywacke	Drained, two dams in lagoon bed	Old drain non-functional, bore in catchment.
	Pansyfields	Private	30°28′44″S 151°32′32″E	1079	2	Basalt	Drained	Very shallow.
	Saumerez Ponds	Private	30°29′23″S 151°33′49″E	1050	24	Basalt	Impounded then drained	Vegetation more or less intact but outlet slightly lowered. Pipe in dam wall to allow drainage.
	Tanglewood (Nandewar)	Private	30°29′52″S 151°36′02″E	1086	3	Basalt	Dam in lagoon bed	Dam spoil used to extend landing strip along lagoon edge.
	Green Wattle	Private	30°30′52″S 151°36′27″E	1070	2	Basalt	Dam in lagoon bed 1992	Shallow.

Lagoon Group	Lagoon	Tenure	Lat/Long	Altitude (m)	Basin area (ha)	Parent material	Hydrological disturbance	Notes
	Pinegrove (Saumerez Airport)	Private	30°31′24″S 151°33′58″E	1044	3	Basalt	Small dam at one end	Essentially intact but soil disturbed by cattle trampling and worm digging.
	Wyanbah (Airport)	Crown Land	30°31′51″S 151°37′18″E	1086	4	Basalt		Essentially intact, minor soil excavations around edge for road building.
	Dangarsleigh	Private	30°38′00″S 151°41′16″E	1043	1	Basalt	Drained then impounded	Very shallow, margin eroded. Drained long ago, dam wall erected across drain.
	Thomas	Private	30°32′44″S 151°33′13″E	1034	4	Basalt/ silcrete		Essentially intact. Two outlets, apparently slightly lowered.
	Strahle	Private	30°32′51″S 151°32′27″E	1043	6	Basalt	Drained	Old drain, much trampled by cattle.
	Sawpit Swamp	Private	30°31′28″S 151°32′07″E	1062	<1	Basalt		Very shallow.
	Barleyfields - Uralla	TSR	30°37′24″S 151°31′42″E	1069	6	Basalt	Minor	Small dam above margin, worm digging. Old highway partially encroaches on western side.
Uralla	Dangars	TSR	30°40′53″S 151°30′12″E	1022	55	Granite-derived sediment	Impounded	Extensive wall erected in 1850s to increase capacity for use in goldmining. May have once been more extensive.
	Racecourse	Uralla Shire	30°40′23″S 151°29′30″E	1030	20	Granite		Intact. Racetrack around edge, also boating. Lagoon bed ploughed in 1980s to grow oats.
	Kentucky	Private	30°45′″S 151°26′″E	1062	4	Porphyrite	Drained	Drained long ago.
	Taylors	Private	30°46′07″S 151°27′20″E	1050	7	Diorite	Shallow drain	
Walcha	Round Swamp	Private	31°12′19″S 151°42′33″E	1276	45	Basalt	Drained then impounded	Impounded in late 1990s across old drain. Total loss of wetland vegetation by 2004.
	The Lakes (Brackendale)	Private	31°13′23″S 151°41′28″E	1264	20	Basalt	Impounded	Total loss of wetland vegetation.
	Yarrowitch	State Forest	31°17′40″S 151°58′25″E	1128	8	Basalt	Drained	System of drains in lagoon bed, outlet lowered.
	New Country Swamp	National Park	31°19′42″S 151°52′10″E	1166	15	Basalt/slate		Essentially intact. Outlet affected by road to picnic area but apparently not raised.
	South Head	State Forest	31°27′35″S 151°16′55″E	1210	<1	Basalt/slate		Very shallow. Margin no longer intact due to erosion.

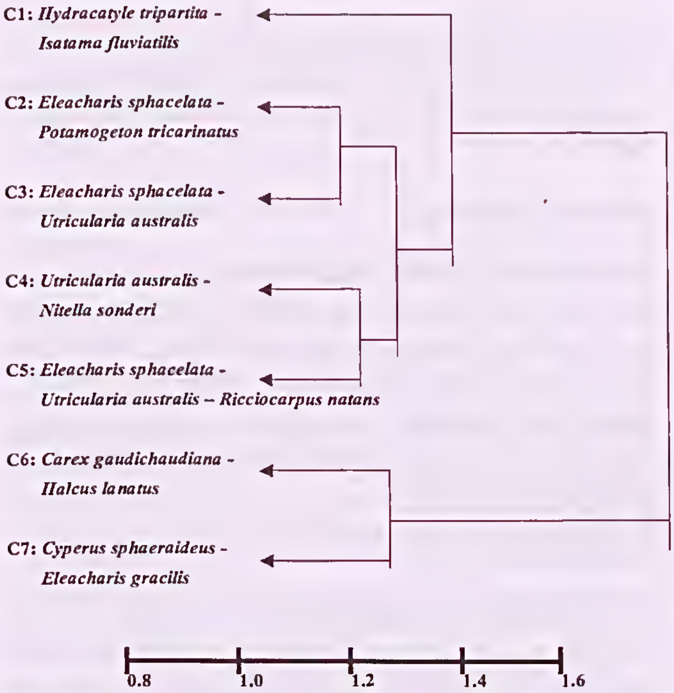
C1: Hydracatyle tripartita - Isatama fluviatilis
C2: Eleacharis sphacelata - Potamogeton tricarinatus
C3: Eleacharis sphacelata - Utricularia australis
C4: Utricularia australis - Nitella sonderi
C5: Eleacharis sphacelata - Utricularia australis – Ricciocarpus natans
C6: Carex gaudichaudiana - Halcus lanatus
C7: Cyperus sphaeraideus - Eleacharis gracilis
0.8
1.0
1.2
1.4
1.6

Fig. 2. Summary dendrogram of full dataset of sites using Kulczynski association and flexible UPGMA fusion strategy.

Analyses and data exploration used options available in the PATN Analysis Package (Belbin 1995a). For the final presentation, all species and their relative cover scores were included, and the analysis performed used the Kulczynski association measure recommended for ecological applications (Belbin 2004), along with flexible Unweighted Pair Group arithmetic Averaging (UPGMA) and the default PATN settings. Community structural names are based on the most consistently dominant taxa or, in the case of *Eleocharis sphacelata*, on the tallest emergent taxa. Semi-Strong- Hybrid Multidimensional Scaling (SSH) was used as the ordination technique. Multidimensional scaling (MDS) moves objects around in a space defined by the number of dimensions chosen and the dissimilarities among sites in terms of their composition (Belbin 1991b). SSH calculates the level of stress, which is the miss-match between distances between points and the best estimate of the same values (Belbin 1995b). Simple regression was used to follow the changes in species richness against basin depth.

Results

Lagoon site details and condition

We identified 58 montane lagoons in the New England Tablelands Bioregion (Table 1). These wetlands are most common in the Guyra-Llangothlin area and west of Armidale, with scattered sites near Glen Innes, Uralla and south of Walcha (Fig. 1). While this list is comprehensive for known lagoons, it is likely that others on basalt-derived terrain may yet be undiscovered.

Lagoons range in altitude from 930 m (Kings Plains) to over 1360 m (Billybung, South Llangothlin), and from Kings Plains northwest of Glen Innes in the north to just north of Hanging Rock in the south (Fig. 1). Wetlands range in size from less than 1 ha to 430 hectares. Only two, Mother of Ducks (430 ha) and Llangothlin (410 ha) are substantial in size; two others, Clarevaulx (140 ha) and Little Llangothlin (100 ha) are moderately large; 16 are of medium size (10 –100 ha), the largest of these is Pinch Lagoon at 43 ha. The remainder (66 %) are small (<10 ha) with 6 of these less than 1 ha in area.

22 lagoons have more or less intact basins supporting wetland vegetation. Of these, five are small and very shallow and only hold water intermittently, and in a further two (Strahles, Blair Hill) the basin sediments are much disturbed by cattle trampling and the vegetation appears restricted to no more than a handful of species. Only 15 (28%) of lagoons could be considered intact and in good condition. Only one of each of the two substantial and two large lagoons (respectively, Llangothlin and Little Llangothlin) is intact. Of the 16 medium lagoons, only four (25%) are intact and of the 38 small lagoons, only nine (24%) are intact or deep enough to hold water frequently.

Disturbance to basin hydrology is common; lagoons have been drained, impounded or have had dams sunk into basin floors. Drainage has involved simply a lowering of the outlet (which usually requires cutting through a layer of ferricrete) or lowering of the outlet in conjunction with drainage via either a single central drain (Edenglen) or a network of drains (Clarevaulx, Glen Athol West). Mother of Ducks lagoon outlet has been lowered by a massive 2 m. A large central ditch excavated into the basin at Brockley Swamp cuts through the lagoon margin; water now drains in the opposite direction to the original overflow outlet. The outlets of three lagoons (Llangothlin, Little Llangothlin and Kolara) have been restored to their approximate original levels after past lowering. Other disturbances include the construction of a wall across part of the basin to prevent water reaching private grazing and cropping land (Reddestone). Roadworks or airstrips impinge on the edges of some lagoon basins (Glen Athol West, Barleyfields-Uralla, Tanglewood). Three lagoons (Dangars, Barleyfields-Uralla and Edenglen) provided water for nineteenth century goldmining (*pers. com.* Arnold Goode, Ron Sisson). Pinegrove and Barleyfields-Uralla are often subject to worm-digging to provide fishing bait. Previous recreational uses of the lagoons included boating (Racecourse, Mother of Ducks) and public swimming events (Dangars).

Almost all lagoons (85 %) occur on private property. Only six are on public land with a further three partly on public and partly on private land (Billybung, Mother of Ducks, Reddestone). All but five lagoons (Little Llangothlin, Racecourse, New Country Swamp, part of Mother of Ducks, Billybung) are currently grazed by cattle; a few lagoons are grazed only by sheep (Wyanbah, Kolora).

Vegetation patterns

Seven communities were defined at a dissimilarity of 0.9 (Fig. 2) and these occurred within three major divisions (Figs. 2 & 3). These major divisions highlight an inferred water depth environmental gradient running from the top right hand corner to the bottom left hand corner of the ordination (Fig. 3).

Floristics

A total of 173 vascular plant taxa in 48 families and 117 genera were recorded from the six sites (94 taxa), and from opportunistic collections at other lagoons over 16 years (an additional 86 taxa). Six charophytes (in the genera *Chara* and *Nitella*) and one large floating liverwort were also recorded. Families with the most taxa overall were: Poaceae (28 species), Cyperaceae (25 species) and Asteraceae (24 species). The richest genera were: *Juncus* (9 species), *Eleocharis* (6 species), *Cyperus* (6 species) and *Carex* (5 species). 43 taxa overall (24 %) were exotic but only 9 exotic taxa were recorded in the transect survey (10 %).

The most frequent species encountered was *Myriophyllum variifolium*, recorded in 52 of the 68 plots (76 %). Other frequent species were *Glyceria australis*, *Hydrocotyle tripartita*, *Utricularia australis*, *Eleocharis pusilla*, *Eleocharis dietrichiana*, *Potamogeton tricarinatus* and *Isotoma fluviatilis* subsp. *borealis*.

Most taxa displayed an emergent life form but there were 5 submerged species, 7 floating leaved species, 3 free-floating species and 2 floating-submerged species. 18 strictly terrestrial species were recorded from drained and shallow lagoons.

Vegetation assemblages

Physiographic Position: Lagoon edges

Restricted, in unmodified systems, to the lagoon edge towards the top of basin slopes at study sites but commonly occurs over the whole basin if very shallow (drained or in-filled).

Community 1: *Hydrocotyle tripartita – Isotoma fluviatilis – Ranunculus inundatus – Lilaeopsis polyantha* herbfield

Environmental relationships: Water-level fluctuations are a feature of this habitat; many species here belong to Brock and Casanova (1997)'s amphibious group.

Emergent: *Myriophyllum variifolium, Eleocharis pusilla, Hydrocotyle tripartita, Isotoma fluviatilis* subsp. *borealis, Lilaeopsis polyantha, Eleocharis dietrichiana, Ranunculus inundatus, Glyceria australis, Eleocharis acuta, Lachnagrostis filiformis, Brachyscome radicans, Stellaria angustifolia, Crassula helmsii, Isolepis fluitans, Cyperus sanguinolentus, Gamochaeta americana, Myriophyllum lophatum, Epilobium billardierianum* subsp. *hydrophilum, Juncus fockei, Holcus lanatus, Elatine gratioloides, Rorippa palustris, Amphibromus nervosus, Panicum obseptum, Juncus vaginatus, Carex gaudichaudiana, Amphibromus sinuatus, Persicaria hydropiper, Eragrostis* sp., *Utricularia dichotoma, Spirodela punctata, Ricciocarpus natans, Limosella australis, Eleocharis sphacelata, Pennisetum alopecuroides,*

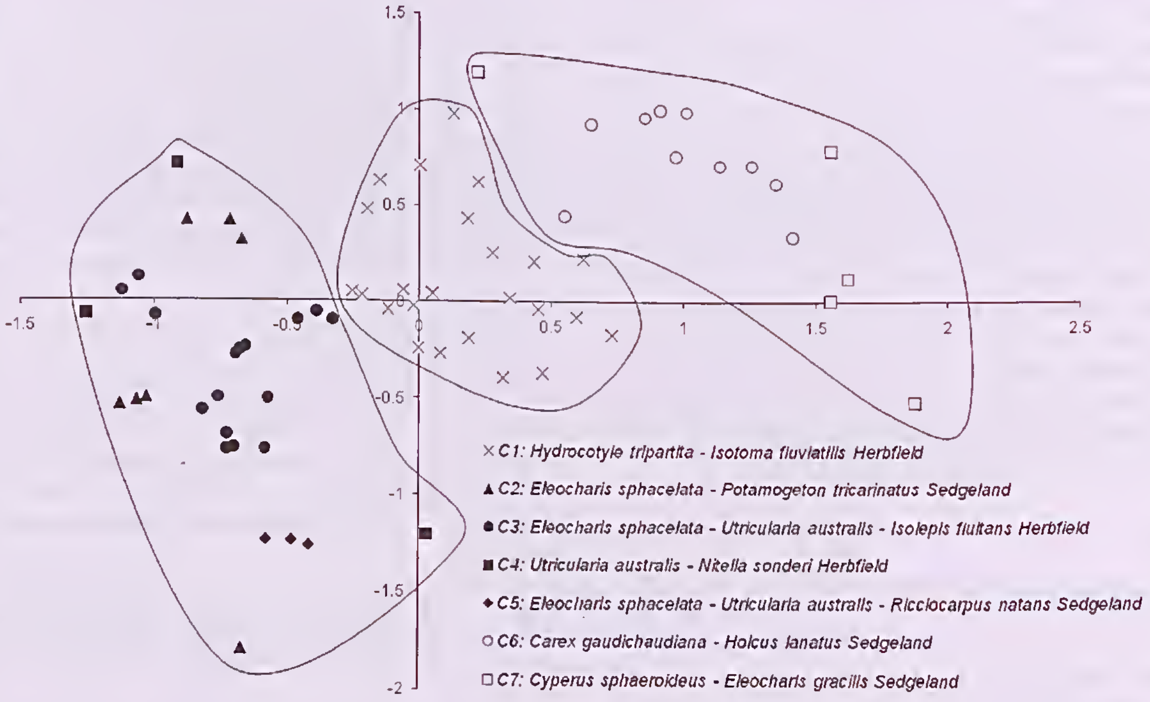

Fig. 3. Ordination scattergram of seven lagoon communities within three major physiographic groups using flexible UPGMA and SSH (Belbin 1995a). Basin depth increases from right to left.

Paspalum distichum, Juncus articulatus, Hemarthria uncinata, Schoenus apogon, Juncus bufonius, Euchiton involucratus, Centipeda minima, Rumex crispus, Hypericum japonicum, Asperula charophyton, Trifolium repens.

Floating-leaved: *Nymphoides montana, Potamogeton tricarinatus, Nymphoides geminata, Brasenia schreberi.*

Floating-submerged: *Aldrovandra vesiculosa, Utricularia australis.*

Variability: Recorded at all six sites. A generally species-rich community (mean richness 15, range 11–23) with fewer species at the very shallow temporary Wyanbah Lagoon.

Notes: In most drained lagoons and in shallow, presumably long in-filled lagoons, elements of this community occur across the whole basin. Often, where substantial hydrological disturbance has occurred, a few species of this community (e.g. *Hydrocotyle tripartita* and *Lachnagrostis filiformis*) are the only wetland species that remain, occurring alongside common terrestrial pasture species, both exotic and native.

Physiographic Position: Lagoon basins

Restricted to the lagoon basin in deeper water. Generally only occurs in intact lagoons with little or no hydrological disturbance. Elements of this community (*Eleocharis sphacelata* and *Myriophyllum variifolium*) may occur in some in-filled lagoons (Wyanbah, Barleyfields) and in some drained lagoons (Edenglen).

Community 2: *Eleocharis sphacelata – Potamogeton tricarinatus* sedgeland

Environmental relationships: Occurring in deepest parts of some lagoons.

Emergent: *Eleocharis sphacelata, Myriophyllum variifolium, Glyceria australis, Eleocharis dietrichiana, Panicum obseptum.*

Floating-leaved: *Potamogeton tricarinatus, Nymphoides montana, Nymphoides geminata.*

Variability: In the transect survey only recorded in the shallow Wyanbah, in Little Llangothlin Lagoons and at the northern end of Llangothlin Lagoon.

Notes: Characterised by high cover and abundance of both *Eleocharis sphacelata* and *Potamogeton tricarinatus* (where it occurs). In Little Llangothlin Lagoon often an *Eleocharis sphacelata* monoculture. This community is characterised by low species richness (4.4, range 1–8) and the floating submerged plant *Utricularia australis* is absent (compare to Communities 3, 4 and 5).

Community 3: *Eleocharis sphacelata – Utricularia australis – Isolepis fluitans* herbfield

Environmental relationships: Occurring in deeper parts of smaller or shallower lagoons and at intermediate depths of large, deeper sites.

Emergent: *Myriophyllum variifolium, Isolepis fluitans, Eleocharis sphacelata, Glyceria australis, Isotoma fluviatilis* subsp. *borealis, Hydrocotyle tripartita, Brachyscome radicans, Amphibromus sinuatus, Ranunculus inundatus.*

Floating-leaved: *Potamogeton tricarinatus, Nymphoides montana.*

Floating submerged: *Utricularia australis.*

Variability: In the transect survey found at all sites except Wyanbah. Not present at Little Llangothlin Lagoon where intermediate depths were mostly open water.

Notes: Essentially represents communities at intermediate depths where relatively shallow water and vegetation cover prevent disturbance by wind. Extensive in the deeper centre of Little Llangothlin Lagoon and covers almost the whole surface of Llangothlin Lagoon except for part of the southern end where open water and stands of *Myriophyllum variifolium* are common. Mean richness six (range 3–11).

Community 4: *Utricularia australis – Nitella sonderi* herbfield

Environmental relationships: Occurring at sheltered intermediate depths of large lagoons where cover of emergents and floating-leaved plants is low and patchy.

Emergent: *Myriophyllum variifolium, Isolepis fluitans, Paspalum distichum, Eleocharis pusilla.*

Floating: *Ricciocarpus natans.*

Floating-leaved: *Potamogeton tricarinatus.*

Floating-submerged: *Lemna trisulca, Utricularia australis.*

Submerged: *Nitella sonderi, Nitella cristata, Chara muelleri, Potamogeton crispus, Najas tenuifolia.*

Variability: Only found in the transect survey at the southern end of Llangothlin Lagoon but noted on other occasions at Racecourse (Casanova 1993) and Little Llangothlin Lagoons.

Notes: Characterised by submerged species, sparse cover of emergents and floating-leaved species and relatively high light penetration into the water column. Low richness (7.7, range 7–9) and extreme patchiness of all species is a feature of this community.

Community 5: *Eleocharis sphacelata – Utricularia australis – Ricciocarpus natans* sedgeland

Environmental relationships: Occurring in sheltered deeper parts of large lagoons.

Emergent: *Myriophyllum variifolium.*

Floating: *Ricciocarpus natans.*

Floating-submerged: *Lemna trisulca.*

Submerged: *Utricularia australis.*

Variability: Southern end of Llangothlin Lagoon only.

Notes: Characterised by floating and floating-submerged species in sheltered relatively deep water between clumps of *Eleocharis sphacelata* and low cover of emergents such as *Myriophyllum variifolium.* Low richness (5, range 4–5).

Physiographic Position: Lagoon margins

Restricted to damp lagoon margins at or near the high water mark and fed by seepage.

Community 6: *Carex gaudichaudiana – Holcus lanatus – Stellaria angustifolia* sedgeland

Environmental relationships: Occurring at damp margins of lagoons at approximately high water mark where seepage is present.

Emergent: *Holcus lanatus, Glyceria australis, Carex gaudichaudiana, Stellaria angustifolia, Hydrocotyle tripartita, Eleocharis dietrichiana, Eleocharis pusilla, Eleocharis acuta, Epilobium billardierianum* subsp. *hydrophilum, Lachnagrostis filiformis, Asperula charophyton, Neopaxia australasica, Anthoxanthum odoratum, Isolepis fluitans, Gamochaeta americana, Myriophyllum variifolium, Isotoma fluviatilis* subsp. *borealis, Brachyscome radicans, Trifolium repens, Viola betonicifolia, Juncus fockei, Spiranthes sinensis, Myriophyllum lophatum, Amphibromus nervosus.*

Variability: Within the transect survey only at Billybung and Little Llangothlin Lagoons but common at many other sites where seepage occurs at margins at the base of basalt slopes (e.g. parts of Kolora and Pinch Lagoons, Thomas Lagoon and Abbey Green Lagoon). A relatively rich community (9.9, range 7–15).

Notes: Appears to be a transitional community not strictly part of the lentic wetland but fed by seepage from the surrounding slopes, similar to *Carex* sedgelands of swampy, drainage line and creek-line areas in other parts of the Northern Tablelands.

Community 7: *Cyperus sphaeroideus – Eleocharis gracilis – Schoenus apogon – Carex gaudichaudiana* sedgeland

Environmental relationships: Restricted to damp margins of Llangothlin Lagoon at approximately high water mark and fed by seepage from the base of the slope and from the lunette.

Emergent: *Cyperus sphaeroideus, Eleocharis gracilis, Hydrocotyle tripartita, Holcus lanatus, Hypericum japonicum, Eragrostis* sp., *Schoenus apogon, Stellaria angustifolia, Carex gaudichaudiana, Pennisetum alopecuroides, Myriophyllum lophatum, Epilobium billardierianum* subsp. *hydrophilum, Ranunculus lappaceus, Gamochaeta americana, Sacciolepis indica, Hemarthria uncinata, Hypochaeris radicata, Brachyscome radicans, Trifolium repens, Eriocaulon scariosum, Prunella vulgaris, Lachnagrostis filiformis, Crassula helmsii, Glyceria australis, Arthraxon hispidus, Gonocarpus micranthus, Leucanthemum vulgare, Leiocarpa* sp. 'Uralla' (D.M. Bell), *Eryngium* sp. 'Little Llangothlin NR' (D.M. Bell 5 6) A, *Eleocharis dietrichiana, Neopaxia australasica, Lilaeopsis polyantha, Euchiton involucratus, Spiranthes sinensis, Isotoma fluviatilis* subsp. *borealis, Eleocharis atricha, Festuca elatior, Austrostipa inaequiglumis, Amphibromus nervosus, Hydrocotyle peduncularis, Isolepis fluitans, Dichondra repens, Haloragis heterophylla, Hypoxis hygrometrica, Juncus vaginatus, Juncus articulatus, Juncus bufonius, Microtis unifolia, Phragmites australis, Solenogyne bellioides, Utricularia dichotoma.*

Floating leaved: *Potamogeton tricarinatus.*

Variability: Only at Llangothlin Lagoon margins close to granite-derived soil and the sandy lunette.

Notes: Similar to Community 6 but more species-rich (mean 25, range 21–31), similar in part to *Carex* sedgelands.

Environmental gradients and community distribution

Species richness generally decreases with depth (Fig. 4) and communities at lagoon margins are consistently richer in species than those in deeper water. Margin communities typically occupy only a small part of the basin (Figs. 5 and 6), and edge (Community 1) and deeper communities (e. g. Communities 4 and 5) are more extensive (Communities 6 and 7).

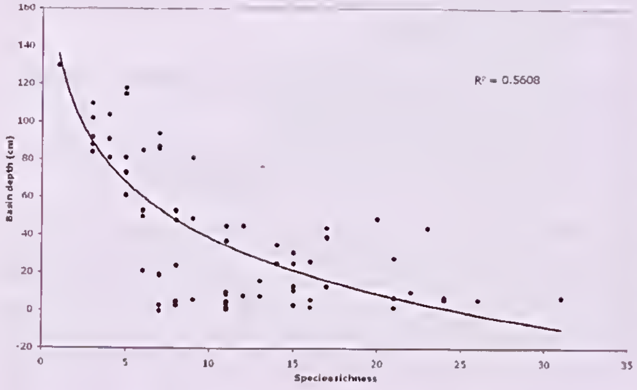

Fig. 4. Relationship between species richness and basin depth in six lagoons on the Northern Tablelands Bioregion of New South Wales.

All but a few lagoons have basaltic substrate and those that are on other bedrocks (e.g. Racecourse, Kyoma) are close to the edge of basaltic landscapes and are thought to have developed on them (Walker 1977; Haworth 1994). The influence of acid granite soils is seen particularly at the margins of Llangothlin and Little Llangothlin where soils have a high sand content (Bell 2000) and species such as *Baloskion stenocoleum* and *Eleocharis atricha*, that are more typical of acidic soils, occur.

Discussion

Distribution and extent

Lagoons are more numerous and extensive than previously described (Walker 1977; Keith 2004). Of the 58 lagoons identified all but New Country Swamp contain or potentially contain the listed Endangered Ecological Community. Many more may have been lost due to drainage or natural in-filling processes or to in-filling exacerbated by clearing and grazing (Haworth 1994; Haworth & Gale 1999). Some landholders refer to parts of their property that briefly hold water after rain – no doubt some of these areas were lagoons that have become silted up by natural processes and erosion.

Spatial and Temporal Variability

At the regional scale, under the higher rainfall conditions of this part of the region, the remaining intact lagoons south of Walcha e.g. New Country Swamp, appear to develop vegetation that is more typical of *Carex* sedgelands, especially when they have been drained. Round Swamp was a *Carex appressa* sedgeland before it was impounded and Yarrowitch has *Carex* sedgeland in and near the drains but lagoon vegetation in other parts.

Differences due to size, depth and hydrology are apparent at the wetland scale. The small, shallow Wyanbah lagoon contained only 2 communities; drained or shallow lagoons often contain a species-poor version of Community 1. Larger and deeper intact lagoons feature more habitat diversity and several floristically distinct communities or zones may co-exist in the same wetland (Fig. 5).

The majority of lagoons (including all drained and shallow lagoons) are temporary, and hold water for only short periods each year or only in wet years. Only two the largest could be termed semi-permanent (Little Llangothlin, Llangothlin) and even these have been known to dry completely in severe droughts. The transect survey thus represents the vegetation of these sites at one point in time. Lagoon vegetation is highly dynamic, both within a growing season (Bell 1991), and over a number of years in response to changes in water depth and to water level history (Bell 2000). A drought may see that part of Llangothlin Lagoon, which in 1998 supported the *Utricularia australis – Nitella sonderi* community, covered with terrestrial plants such as *Conyza bonariensis* and *Persicaria* sp. Even where the species mix is the same, for example, in the edge Community 1, under some conditions, different species such as *Myriophyllum variifolium* (wetter) or *Hydrocotyle tripartita* (drier) may dominate. Many of the species respond to deeper water by altering growth-forms (Brock & Casanova 1997), but survive in dry sediments by means of seeds, tubers (*Potamogeton tricarinatus*) or dormant winter buds (*Utricularia australis, Aldrovanda vesiculosa*).

Because of temporal and within wetland variation, vegetation description in these, as in other dynamic systems, is problematic (Bell 2000). Although vegetation at the regional or whole wetland scale is appropriate for large-scale mapping (Benson & Jacobs 1994; Benson & Ashby 2000), broad descriptions ignore, of necessity, a wealth of detail that occurs at finer grains. Species richness, for example, varies strongly with depth (Figs 4 and 5). Thus though full wetland presence/abundance lists imply that all species co-exist, our study suggests that this is not always the case. At finer grains, differences among within-lagoon communities emerge that may be more important to the functioning of these systems than differences between lagoons.

Associations with other vegetation types

Seepage as a source of moisture is a feature of the lagoons whose catchments include basalt slopes or lunettes; the moisture in these areas is probably not static, but drains slowly through the soil, rather than ponding. Of the other two major wetland types in the Bioregion, the vegetation of these seepage areas (Communities 6 and 7) shares many species with the nutrient-rich *Carex* sedgelands, but few species (*Gonocarpus micranthus, Baloskion stenocolemn*) with the nutrient-poor and acidic bogs (Hunter & Bell 2007), and then only where granitic soils occur on margins. Under wet conditions, lagoons share few species with terrestrial communities, but opportunistic or weedy species, both native (*Asperula conferta*) and exotic (*Cirsium vulgare*) colonise damp mud during dry times.

Reservation and conservation issues

Lagoons on private property (85 %) are potentially vulnerable to damaging landuse activities; these usually involve some sort of hydrological disturbance. Since 1994 one site has been impounded, and dams excavated into the basins of two other sites. Impoundment has the potential to create a permanent reservoir and to literally 'drown' all within-basin vegetation. An example of the vulnerability of these wetlands, and of landholder interactions is illustrated by recent events at Pinch Lagoon. Although the outlet of Pinch Lagoon has been lowered, there are drainage ditches along the lagoons margins, and sufficient water remains in the basin to support extensive wetland vegetation. The principal landholders value the fodder provided (mostly *Glyceria australis* with some *Eleocharis sphacelata*), and cattle frequently graze in deep water. The wetland drains into another property; where the owner partially filled in the drain, raising water levels in the lagoon, risking a reduction in *Glyceria* cover and reducing the value of the vegetation as fodder (*pers. com.*, Madge Sole, October 2006).

Although most lagoons are grazed, moderate grazing does not appear to have a deleterious affect on vegetation, except in those situations (Strahles, Blair Hill) where trampling in deep mud or peat in shallow basins destroys vegetation.

A low abundance of 'true' aquatic species such as submerged, floating and floating-leaved species is a feature of most lagoon communities. These species are most at risk from changing hydrology as few of them can survive prolonged absence of a water column, although the floating-leaved *Nymphoides montana* and *Potamogeton tricarinatus* can survive on damp mud for some time. Thus the communities most at risk of changes to hydrology are the deeper water Communities 2 to 5. Some species (*Eleocharis sphacelata*) persist in drained lagoons but seed production on dry soil is poor to absent. Other species may disappear altogether with a resulting reduction in the invertebrate and other faunal species that depend on that particular mixture of exposed water column and plant architecture.

Small lagoons and drained lagoons tell us what these wetlands could be like under severe hydrological changes. With a reduction in the duration of the inundation period, the small wetlands become an expanded edge community (Community 1). Where larger wetlands have been drained (Pinch, Saumerez Ponds), the distribution of edge species appears to have expanded to cover the whole wetland. However these shallow wetlands, as well as being the most abundant in the Bioregion, are valuable remnant systems as the species in them are usually strictly wetland species, and, as we have shown (Fig. 4), lagoon edges are more species-rich than other communities.

As with montane bogs (Hunter & Bell 2007), lagoons are at their northern limits in the New England Tablelands Bioregion and are thus susceptible to long-term changes in climate. Suggested impacts of climate change here are higher temperatures and increased rainfall seasonality (Hennessy et al. 2004). Dry periods are likely to be prolonged, and evapotranspiration will increase due to higher overall temperatures. Some lagoon species may disappear, to be replaced by more opportunistic species; the communities that require deeper sheltered water may be lost despite a store of viable diaspores in the sediments. The floating-leaved *Nymphoides montana* may be replaced by *Nymphoides geminata*, a plant of temporary wetlands (as has happened in part of Wyanbah Lagoon). The extensive (approx. 400 ha) *Eleocharis sphacelata – Potamogeton tricarinatus*

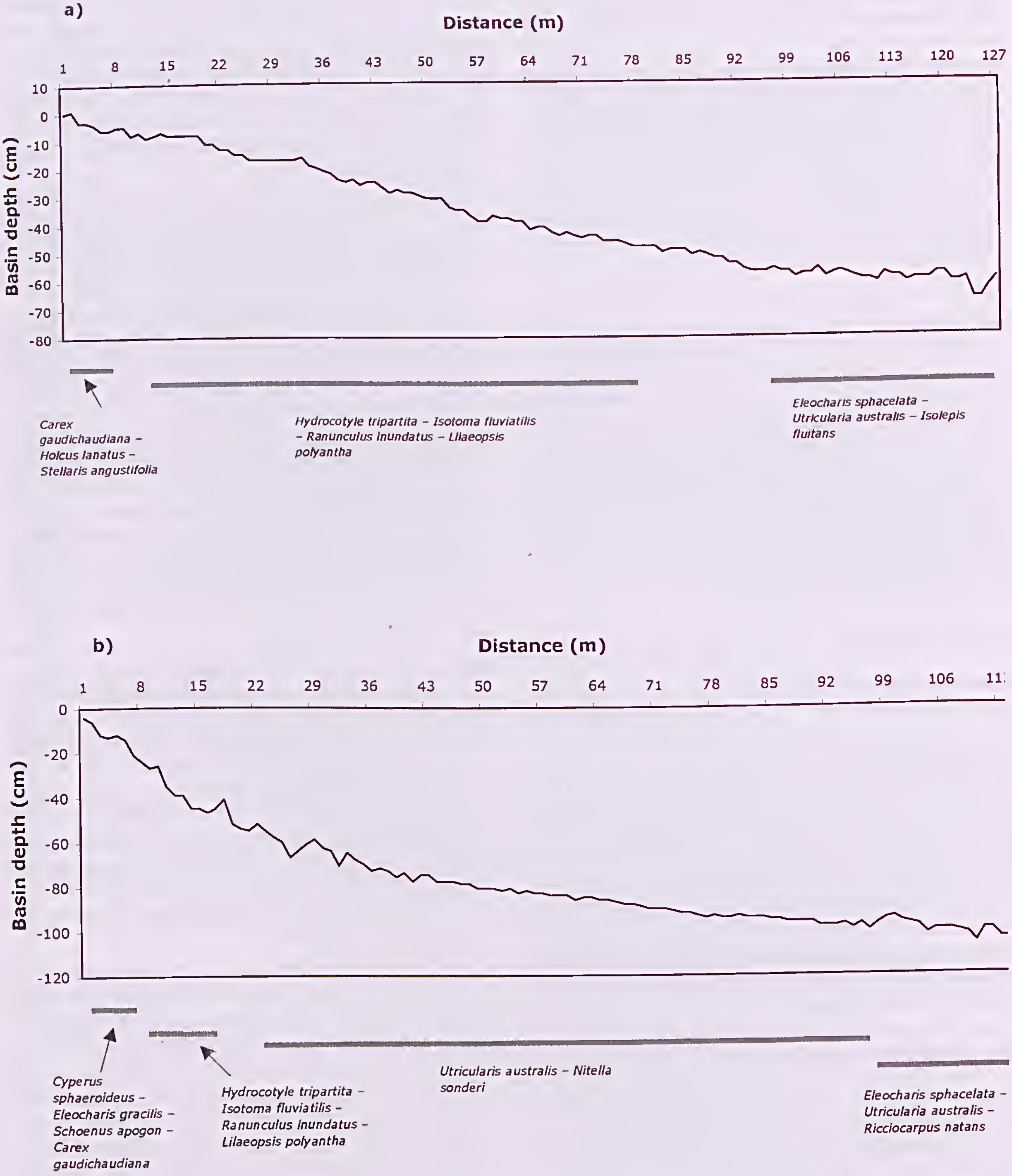

Fig. 5. Distribution of communities in two lagoons a) transect 3, Billybung, b) transect 4, Llangothlin (south end).

community of Llangothlin Lagoon could become more like the hybrid edge/deep community of Wyanbah and Saumerez Ponds with the loss of many plant and fauna species. Although seedbanks in these wetlands are long-lived (Brock 1997; Bell 2004), the potential impacts of prolonged dry periods on oospores, seeds and other propagules require investigation.

Management: retaining intermittence and semi-permanence

On geological time scales wetlands are temporary features of the landscape and have probably been slowly filling with sediment since the cessation of the active basin deflation period. Thus we need to be realistic about potential changes to these systems, particularly as we have no records of the sort of communities these basins supported before the beginning of sheep grazing in the Tablelands in the 1850s (Haworth 1994). We can, however, predict with some certainty what the present wetlands will become if drainage continues.

At shorter time scales, what is certain is that in these systems the diversity of habitat and species depends on the diversity of wetting and drying cycles (Brock et al. 1999). Restoring lagoon outlets to their original levels (Little Llangothlin Lagoon) should, in time, restore habitat diversity. The ditch and levee system, created in part of a large degraded lagoon basin to maintain bird habitat (Mother of Ducks Lagoon), is in fact, an artificial wetland, and may not be as successful. Although the original basin floor supported the weedy species *Juncus articulatus*, flooding that part of the basin within the levee did not appear to reduce the abundance of that species (Smith & Brock 1996). The reserve is now undergoing invasion by the native but weedy *Carex fascicularis*.

In 1998 a few plants of the exotic weedy species *Ranunculus sceleratus* appeared at the edge of Dangars Lagoon. By 2006, the population there was substantial, and scattered plants have appeared at Racecourse and Little Llangothlin Lagoons. This species, a coloniser of bare mud and dispersed by waterbirds, and is of particular concern to those wetlands where expanses of bar mud are common.

Rare or restricted plant species

There are 22 taxa of conservation significance in these wetlands. *Aldovandra vesiculosa* is currently listed as Endangered and *Arthaxon hispidus* as Vulnerable under the NSW *Threatened Species Conservation Act 1995*. Three taxa have been reported under the RoTAP criteria (Briggs & Leigh 1996): *Asperula charophyton* (3RCa), *Brasenia schreberi* (3RC-) and *Goodenia macbarronii* (3VC).

Three additional taxa are of significance:

Plantago sp. nov. The edge of Billybung Lagoon contains one of the only two known populations of *Plantago* sp. nov. (*pers. com.* Lachlan Copeland).

Eryngium sp. 'Little Llangothlin NR' (D.M. Bell 5 6), also known from the ACT, this species occurs within the Bioregion almost exclusively as small scattered populations on the margins or edges of lagoons (Billybung, Llangothlin, Edenglen, Thomas and South Head) with the biggest population at Billybung Lagoon.

Both the *Plantago* sp. nov. and *Eryngium* 'Uralla' (D.M. Bell NR 54142) display heterophylly; terrestrial forms have divided leaves, underwater forms undivided.

Leiocarpa sp. 'Northern Tablelands', although fairly common and widespread, also occurs almost exclusively on the margins of lagoons.

A further 14 species are considered as significant due to their being considered regionally uncommon, from depleted habitat or at or near their northern distributional limit (Sheringham & Westaway 1998). These taxa are: *Carex chlorantha*, *Carex tereticaulis*, *Crassula helmsii*, *Elatine gratioloides*, *Eleocharis atricha*, *Glossostigma diandrum*, *Isolepis fluitans*, *Isotoma fluviatilis* subsp. *borealis*, *Lemna trisulca*, *Lipocarpha microcephala*, *Myriophyllum simulans* (not seen in this survey), *Veronica serpyllifolia*, *Lilaeopsis polyantha* and *Juncus filicaulis*. Many of these species, e.g. *Lilaeopsis polyantha*, *Isotoma fluviatilis* subsp. *borealis* and *Isolepis fluitans*, are abundant and widespread in lagoons; it is the particular system that is rare in the landscape, so these species are generally not encountered in general surveys.

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Appendix 1: Floristic composition of lagoons of the New England Tablelands Bioregion.

Taxa found within the survey sites are scored according to their presence in each of the seven communities defined. Other taxa were found in previous surveys (Bell 2000) or opportunistically (Op) and therefore are not assigned to a specific community.
1 = _Hydrocotyle tripartita – Isotoma fluviatilis – Ranunculus inundatus – Lilaeopsis polyantha_ herbfield
2 = _Eleocharis sphacelata – Potamogeton tricarinatus_ sedgeland
3 = _Eleocharis sphacelata – Utricularia australis – Isolepis fluitans_ herbfield
4 = _Utricularia australis – Nitella sonderi_ herbfield
5 = _Eleocharis sphacelata – Utricularia australis –Ricciocarpus natans_ sedgeland
6 = _Carex gaudichaudiana – Holcus lanatus – Stellaria angustifolia_ sedgeland
7 = _Cyperus sphaeroideus – Eleocharis gracilis – Schoenus apogon – Carex gaudichaudiana_ sedgeland

* = introduced in origin. Casanova (1993) was used for non-vascular species and charophyte nomenclature was verified by Michelle Casanova (_pers. com._) Species life history types include: E: emergent; F: free-floating; FS: free-floating submerged, FL: floating-leaved; S: submerged; T: terrestrial.

Species	**Type**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Op**
Alismataceae									
Damasonium minus	FL								O
Amaranthaceae									
Alternanthera denticulata	E								O
Apiaceae									
Centella asiatica	E								O
*_Daucus carota_	T								O
Eryngium sp. 'Little Llangothlin NR'	E							7	
Hydrocotyle peduncularis	E						6		
Hydrocotyle tripartita	E	1		3			6	7	
Lilaeopsis polyantha	E	1						7	
Asteraceae									
Ammobium alatum	T								O
*_Aster subulatus_	E								O
Brachyscome graminea	E								O
Brachyscome radicans	E	1		3			6	7	
Calotis scapigera	E								O
Centipeda minima	E	1							
*_Conyza parva_	E								O
*_Conyza bonariensis_	E								O
*_Cotula coronopifolia_	E								O
*_Crepis capillaris_	E								O
Euchiton involucratus	E	1					6		
*_Gamochaeta americana_	E	1					6	7	
*Hypochaeris glabra	E								O
*_Hypochaeris radicata_	E						6	7	
*_Lactuca serriola_	E								O
Leiocarpa sp. 'Uralla'	E						6		
*_Leucanthemum vulgare_	E						6	7	
Pseudognaphalium luteoalbum	E								O
Solenogyne bellioides	E						6		
*_Sonchus asper_ subsp. _glaucescens_	E								O
*_Taraxacum officinale_	E								O
*_Tolpis umbellata_	T								O
*_Tragopogon dubius_	T								O
*_Xanthium spinosum_	T								O
Azollaceae									
Azolla filiculoides var _rubra_	F								O
Brassicaceae									
*_Rorippa palustris_	E	1							
Cabombaceae		1							
Brasenia schreberi	FL	1							
Campanulaceae									
Wahlenbergia communis	T								O

Caryophyllaceae									
*_Paronychia brasiliana_	E								O
Scleranthus biflorus	T								O
Stellaria angustifolia	E	1					6	7	
Characeae									
Chara corallina	S								O
Chara fibrosa	S								O
Chara muelleri	S				4				
Nitella cristata	S				4				
Nitella sonderi	S				4				
Nitella tasmanica	S								O
Clusiaceae									
Hypericum gramineum	T						6		
Hypericum japonicum	E	1					6	7	
Convolvulaceae									
Dichondra repens	E						6		O
Crassulaceae									
Crassula helmsii	E	1						7	
Cyperaceae		1						7	
Bolboschoenus fluviatilis	E								O
Carex appressa	E								O
Carex fascicularis	E								O
Carex gaudichaudiana	E	1					6	7	
Carex inversa	E						6		
Carex tereticaulis	E								O
Carex sp. 'Bendemeer' (D.M. Bell 296 & J.T. Hunter)									O
*_Cyperus eragrostis_	E								O
Cyperus flaccidus	E								O
Cyperus flavidus	E								O
Cyperus gunnii subsp. _gunnii_	E								O
Cyperus sanguinolentus	E	1						7	
Cyperus sphaeroideus	E						6	7	
Eleocharis acuta	E	1					6		
Eleocharis atricha	E						6	7	
Eleocharis dietrichiana	E	1	2				6	7	
Eleocharis gracilis	E						6	7	
Eleocharis pusilla	E	1			4		6		
Eleocharis sphacelata	E	1	2	3		5			
Fimbristylis dichotoma	E								O
Isolepis cernua	E								O
Isolepis fluitans	E	1		3	4		6	7	
Isolepis habra	E								O
Isolepis hookeriana	E								O
Lipocarpha microcephala	E						6		
Schoenus apogon	E	1					6	7	
Droseraceae									
Aldrovandra vesiculosa	FS	1							
Drosera burmannii	E								O
Drosera peltata	E								O
Elatinaceae		1							2
Elatine gratioloides	E	1							
Eriocaulaceae									
Eriocaulon scariosum	E							7	
Fabaceae									
*_Trifolium arvense_	T								O
*_Trifolium repens_	E	1					6	7	
Gentianaceae									
*_Centaurium tenuiflorum_	T								O
Geraniaceae									
Geranium solanderi var. _solanderi_	E								O
Goodeniaceae									
Goodenia macbarronii	E								O

Haloragaceae									
Gonocarpus micranthus	E						6		O
Haloragis heterophylla	E						6		O
Myriophyllum lophatum	E	1					6	7	
Myriophyllum variifolium	E	1	2	3	4	5	6		
Myriophyllum verrucosum	E								O
Hypoxidaceae									
Hypoxis hygrometrica	E							7	
Iridaceae									
**Sisyrinchium iridifolium*	E								O
**Sisyrinchium* sp. A	E								O
Isoetaceae									
Isoetes drummondii subsp. *anomala*	S								O
Juncaceae									
**Juncus articulatus*	E	1					6		O
Juncus australis	E	1						7	
Juncus bufonius	E	1						7	
Juncus filicaulis	E								O
Juncus fockei	E	1					6		
Juncus homalocaulis	E								O
Juncus subsecundus	E								O
Juncus usitatus	E								O
Juncus vaginatus	E								O
Lamiaceae									
**Prunella vulgaris*	E						6	7	
Lemnaceae									
Lemna trisulca	FS				4	5			
Spirodela punctata	F	1							
Wolffia australiana	E								O
Lentibulariaceae									
Utricularia australis	S	1		3	4	5			
Utricularia dichotoma	E	1						7	
Lobeliaceae									
Isotoma fluviatilis subsp. *borealis*	E	1		3			6	7	
Lythraceae									
Lythrum hyssopifolia	E								O
Malvaceae									
**Malva neglecta*	T								O
**Modiola caroliniana*	T								O
Marsileaceae									
Marsilea costulifera	FL								O
Marsilea hirsuta	FL								O
Menyanthaceae									
Nymphoides geminata	FL	1	2						
Nymphoides montana	FL	1	2	3					
Najadaceae									
Najas tenuifolia	S				4				
Onagraceae									
Epilobium billardierianum subsp. *cinereum*	E								O
Epilobium billardierianum subsp. *hydrophilum*	E	1					6	7	
Orchidaceae									
Microtis unifolia	E							7	O
Spiranthes sinensis subsp. *australis*	E						6	7	
Plantaginaceae									
**Plantago lanceolata*	T								O
Plantago sp. A	E								O
Poaceae									
Austrostipa inaequiglumis	E							7	
Amphibromus nervosus	E	1					6		
Amphibromus sinuatus	E	1		3					
**Anthoxanthum odoratum*	E						6		
**Briza minor*	T								O
Chloris truncata	T								O
Cynodon dactylon	E								O

Deyeuxia quadriseta	E								O
**Eleusine tristachya*	E								O
Eragrostis sp.	E							7	
**Festuca elatior*	E						6		
Glyceria australis	E	1	2	3			6	7	
Hemarthria uncinata	E	1					6	7	
**Holcus lanatus*	E	1					6	7	
Lachnagrostis filiformis	E	1					6	7	
**Lolium perenne*	T								O
Arthraxon hispidus	E							7	
**Panicum gilvum*	E								O
Panicum obseptum	E	1	2						
**Paspalum dilatatum*	E						6	7	
Paspalum distichum	E	1			4				
Pennisetum alopecuroides	E	1					6	7	
Phragmites australis	E							7	
Poa sieberiana	T								O
Sacciolepis indica	E							7	
Sporobolus creber	T								O
Sporobolus elongatus	T								O
**Vulpia bromoides*	T								O
Polygonaceae									
**Acetosella vulgaris*	E								O
Persicaria hydropiper	E	1							
Persicaria lapathifolia	E								O
Persicaria orientalis	E								O
Persicaria prostrata	E								O
**Polygonum arenastrum*	E								O
Rumex brownii	E								O
**Rumex crispus*	E	1							
Portulacaceae									
Neopaxia australasica	E						6		
Potamogetonaceae									
Potamogeton crispus	S				4				
Potamogeton ochreatus	S								O
Potamogeton tricarinatus	FL	1	2	3	4			7	
Ranunculaceae									
Ranunculus inundatus	E	1		3					
Ranunculus lappaceus	E						6		
Ranunculus pimpinellifolius								7	
**Ranunculus sceleratus*	E								O
Ranunculus sp. aff. *lappaceus* (D.M. Bell NE 54120)									O
Restionaceae									
Baloskion stenocoleum	E								O
Ricciaceae									
Ricciocarpus natans									
Rubiaceae									
Asperula charophyton	E	1					6		
Asperula conferta	E								O
Scrophulariaceae		1					6		O
Glossostigma diandrum	E								O
Gratiola peruviana	E								O
Limosella australis	E	1							
**Linaria pelisseriana*	E								O
Mimulus gracilis	E								O
**Veronica anagallis-aquatica*	E								O
Veronica serpyllifolia	E								O
Typhaceae									
Typha domingensis	E								O
Verbenaceae									
**Verbena bonariensis*	E								O
Violaceae									
Viola betonicifolia	E						6		

Flora of the Stockton and Port Hunter sandy foreshores with comments on fifteen notable introduced species.

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Abstract: Between 1993 and 2005 I investigated the introduced plant species on the Newcastle foreshores at Stockton and Macquaries Pier (lat 32° 56' S, long 151° 47' E). At North Stockton in a rehabilitated area, cleared of **Chrysanthemoides monilifera* subsp. *rotundata,* and planted with **Ammophila arenaria* interspersed with native shrubs, mainly *Acacia longifolia* subsp. *sophorae* and *Leptospermum laevigatum*, is a rich flora of introduced species of which **Panicum racemosum* and **Cyperus conglomeratus* have gradually become dominant in the groundcover. Notwithstanding continuing maintenance, **Chrysanthemoides monilifera* subsp. *rotundata* has re-established among the native shrubs, and together with *Acacia longifolia* subsp. *sophorae,* is important in sand stabilisation along the seaward edge of the dune terrace.

The foredune of Little Park Beach, just inside the Northern Breakwater, is dominated by *Spinifex sericeus* and backed by *Acacia longifolia* subsp. *sophorae*-**Chrysanthemoides monilifera* subsp. *rotundata* shrubbery. In places the shrubbery has given way to introduced species such as **Oenothera drummondii*, **Tetragonia decumbens* and especially **Heterotheca grandiflora.*

At Macquaries Pier **Chrysanthemoides monilifera* subsp. *rotundata* forms an almost continuous fringe between the rocks that protect the pier against heavy southerlies. However, its presence on adjacent Nobbys Beach is localised and the general aspect of this beach is no different from any other along the coast as it is dominated by *Spinifex sericeus.*

Many foreign plant species occur around the sandy foreshores at Port Hunter. Since the first coal exports in the 1850s the Newcastle wharves and ballast-ground at Stockton became points of entry for foreign species, either directly, or via stopovers at other Australian ports. Some of these, **Panicum racemosum*, **Tetragonia decumbens*, **Ursinia speciosa,* **Hebenstretia dentata* and until recently, **Heterotheca grandiflora,* remained restricted to the Newcastle region, while others, e.g. **Chrysanthemum monilifera* subsp. *rotundata*, **Hydrocotyle bonariensis*, **Gladiolus gueinzii* and **Oenothera drummondii*, spread further afield, but only colonised their preferred coastal habitat. Many more species spread far and wide, their port of introduction no longer recognisable. Other species were introduced as garden plants, escaped and became naturalised. However, for most foreign, generally widespread, species their mode of entry can no longer be determined. 99 species were recorded in the six areas regularly visited, about 25% native to Australia, and 75% about evenly divided between species from Africa, Asia and Europe. More detailed information on 15 of the more notable introduced species is provided in an appendix.

On the dune terrace vegetation of North Stockton, only about 20% of the 50 species are native to Australia, the only one of any prominence being *Acacia longifolia* subsp. *sophorae*. Nevertheless, on first impression this 'multinational' assemblage looks quite normal, and when one compares the ecological functioning of the 1930s vegetation with that of the present vegetation, it appears that, due to presence of more graminoids, and the fact that **Panicum racemosum* produces a denser sward than *Spinifex sericeus*, the present vegetation is more effective in sand-catching and dune stabilisation than the vegetation in the 1930s would have been. However in view of the increasing influence of climate change, e.g. a rise in sea level and more extreme weather events, there is no indication that the present terrace, notwithstanding the increased density of the rhizomatous species and a sprawling shrubby vegetation along the crest, will endure such attacks any better than in the 1990s.

***Cunninghamia* (2008) 10(3): 493–511**

Introduction

During a reconnaissance of the New South Wales North Coast in 1993 for introduced plant species, the foreshores around Port Hunter provided some unexpected discoveries which triggered follow-up visits to see what else was present. From the first overseas coal exports in the 1850s, Port Hunter (lat 32° 56' S; long 151° 47' E) has been an increasingly busy harbour (Jeans 1972) and over this long period many foreign species could have 'jumped ship.' However, a cursory investigation of the inner harbour foreshores only revealed widespread, usually ruderal exotic species and, hence, my interest remained focused on the seashore on both sides of the harbour entrance (Fig. 1).

Methods

My observations, made between 1993 and 2005, have been limited to walking over the sites and taking notes about occurrence, condition and location of the species seen. Erosion and ongoing foreshore rehabilitation at several sites made it impracticable to establish permanent plots but, given the limited size of the sites, orientation presented no difficulties. I made collections of 47 species for confirmation of identifications or to document their presence. The specimens were lodged in the Australian National Herbarium (CANB) with a duplicate in the National Herbarium of New South Wales (NSW) if there was sufficient material. Introduced species have been preceded with an asterisk throughout the text.

For nomenclature the Flora of New South Wales (Harden 1990–1993, 2002) was used except for two species new for the State. Walsh and Entwisle (1994) was followed for Victoria and Marchant *et al.* (1987) for Western Australia. The specific epithet of **Tetragonia nigrescens* has been changed to *decumbens* (Heyligers 1999b); the taxonomy of *Senecio pinnatifolius* follows Thompson (2005), that of *Ursinia speciosa* Thompson (2007). For some species of special interest, collections in the Australian National Herbarium (CANB), the National Herbarium of New South Wales (NSW) and the Queensland Herbarium (BRI) were inspected. Information on species distribution was obtained from the Flora of New South Wales and checked against the Germplasm Resources Information Network database (http://www.ars-grin.gov/cgi-bin/npgs/html/taxgenform.pl).

Study sites

The foreshore of North Stockton

This area, north of the seawall built to protect the township of Stockton, can be split into four sections, namely the zone seaward of the Corroba Park sports fields, the area between Eames Avenue and the beach, the regularly mown area ('the lawn') along Barrie Crescent and the adjoining dune terrace, separated from the lawn by a shade cloth windbreak fence (Figs. 2 and 3). The Eames Avenue and Barrie Crescent foreshores were overrun by **Chrysanthemoides monilifera* subsp. *rotundata* and have been subject to restoration, while at Corroba Park only a narrow zone along the playing fields has received similar treatment.

The beaches around Port Hunter

Little Park Beach is the southernmost beach of the Stockton foreshore and lies inside the Port between the Northern Breakwater and Pirate Point. It comprises a low, narrow foredune backed by a wider, gently sloping area leading to the Pitt Street Reserve, which is a mainly grassed public park (Fig. 4). Macquaries Pier was constructed between 1818 and 1846 to connect the mainland with Nobbys Island at the mouth of the Hunter River. In the 1870s the pier was reinforced and breakwaters were built to improve access to the Port (Jeans 1972; information on monument at the pier entrance; Fig. 5). The pier obstructed offshore sediment flow which led to the formation of Nobbys Beach. Inside the port, at the base of the pier, lies Horseshoe Beach. This low dune terrace abuts a public reserve and is subject to restoration work.

The local climate

The study area is part of the humid subtropical coast of eastern Australia (de Castro Lopo 1979). The annual rainfall at the meteorological station on Nobbys Head is about 1135 mm. The wetter season, with monthly rainfall averages around 119 mm, starts in March and lasts till June, while from August till November the average rainfall is about 74 mm per month. However, monthly figures vary over a large range; the highest recorded maxima, more than 540 mm, have been in the months of February, March, April and August, while monthly minima may be less than 5 mm at any time of the year (Bureau of Meteorology website).

Average monthly maximum and minimum temperatures range from about 25°C and 19°C during summer to about 17°C and 9°C in winter. The regional wind regime is predominantly onshore, generally light to moderate during summer, but moderate to strong during other seasons, especially in the afternoon when seabreezes come in and displace lighter winds from other directions. Regional tides are semi-diurnal and have an amplitude of about 1.5 m with a daily inequality of about 0.5 m between High Waters (Bureau of Meteorology website and Australian National Tide Tables).

Results

The local flora

The total number of species recorded, including some only found outside the study sites, was just over one hundred, but this is not a complete inventory as some inconspicuous species not in flower will have gone unrecorded. However, I am confident that I have not missed any of the dominant components of the vegetation. Table 1 provides an overview of the species found on the six areas under observation and their distribution. When I analysed the data I was surprised to discover how 'unaustralian' the vegetation on the study sites really is (Table 2a). Only one-quarter of the 99 species listed in the table are indigenous to Australia. 16 of these are limited to coastal habitats including the 10 species used in restoration planting. Some of the latter, e.g. *Acacia longifolia* subsp. *sophorae*, *Leptospermum laevigatum* and possibly *Lomandra longifolia* now spread naturally on the rehabilitated sites. Australian (but non-local) species used in the plantings are *Acacia saligna* from Western Australia and *Casuarina equisetifolia*, the characteristic species of tropical beaches but occurring naturally only as far south as Laurieton on the NSW North Coast (Wilson & Johnson 1990).

A geographical analysis of the 78 introduced species shows that species from Africa, America and Europe (including North Africa and south-western Asia), are represented in about equal proportions, while only ten species have a wider distribution (Table 2b). 18 out of 23 of the African species came from southern Africa, 14 of the 20 American species were from South America, while of the 22 'European' species only four are restricted to Europe. The other 18 are also found in countries bordering the Mediterranean Sea, while many distributions extend into south-western Asia as well, a reflection of the long habitation and commodities interchange in this region.

Many of the foreign species arrived in Australia unnoticed, in ballast or with agricultural imports (Table 3). However, there are also a fair number of ornamental species which escaped from cultivation or persisted after having been discarded as garden waste. Examples of escapees are **Lobularia maritima* and **Gazania rigens*, of discarded plants **Lampranthus multiradiatus* and **Yucca aloifolia*. About one-third of the foreign species are restricted to coastal habitats, but only **Ammophila arenaria* and possibly **Panicum racemosum* were used in the initial stages of dune restoration. The other foreign species are generally widespread occurring along roadsides, on wasteland and in other disturbed environments.

The North Stockton Foreshore

The initial regeneration period of the early 1990s

In the late 1980s the **Chrysanthemoides monilifera* subsp. *rotundata* scrub on the Eames Avenue foreshore was bulldozed into trenches and covered (Conway pers. comm. 1994). Rehabilitation was begun by planting **Ammophila arenaria* on a regular grid and followed up by adding *Acacia longifolia* subsp. *sophorae*, *Leptospermum laevigatum* and *Banksia integrifolia* (Fig. 2b). However, a large seed source of **Chrysanthemoides monilifera* remained on the dunes along the sports field and further to the north. Over time, despite removal efforts, **Chrysanthemoides monilifera* re-established and now, together with *Acacia longifolia* subsp. *sophorae*, forms an integral part in the low shrubbery fringing the immediate shoreline.

During inspections in August 1993 and March 1994, I found a large number of introduced species among the **Ammophila arenaria*, the more common ones being **Oenothera drummondii*, **Hebenstretia dentata*, **Ambrosia artemisiifolia*, **Arctotheca calendula*, **Gazania rigens*, **Lobularia maritima*, **Medicago truncatula*, **Hydrocotyle bonariensis*, **Galenia pubescens* and **Tetragonia decumbens* (Table 1). In addition to *Spinifex sericeus* on the seaward slope, *Senecio pinnatifolius* var. *pinnatifolius* and *Carpobrotus glaucescens* were the only notable native species. *Spinifex*

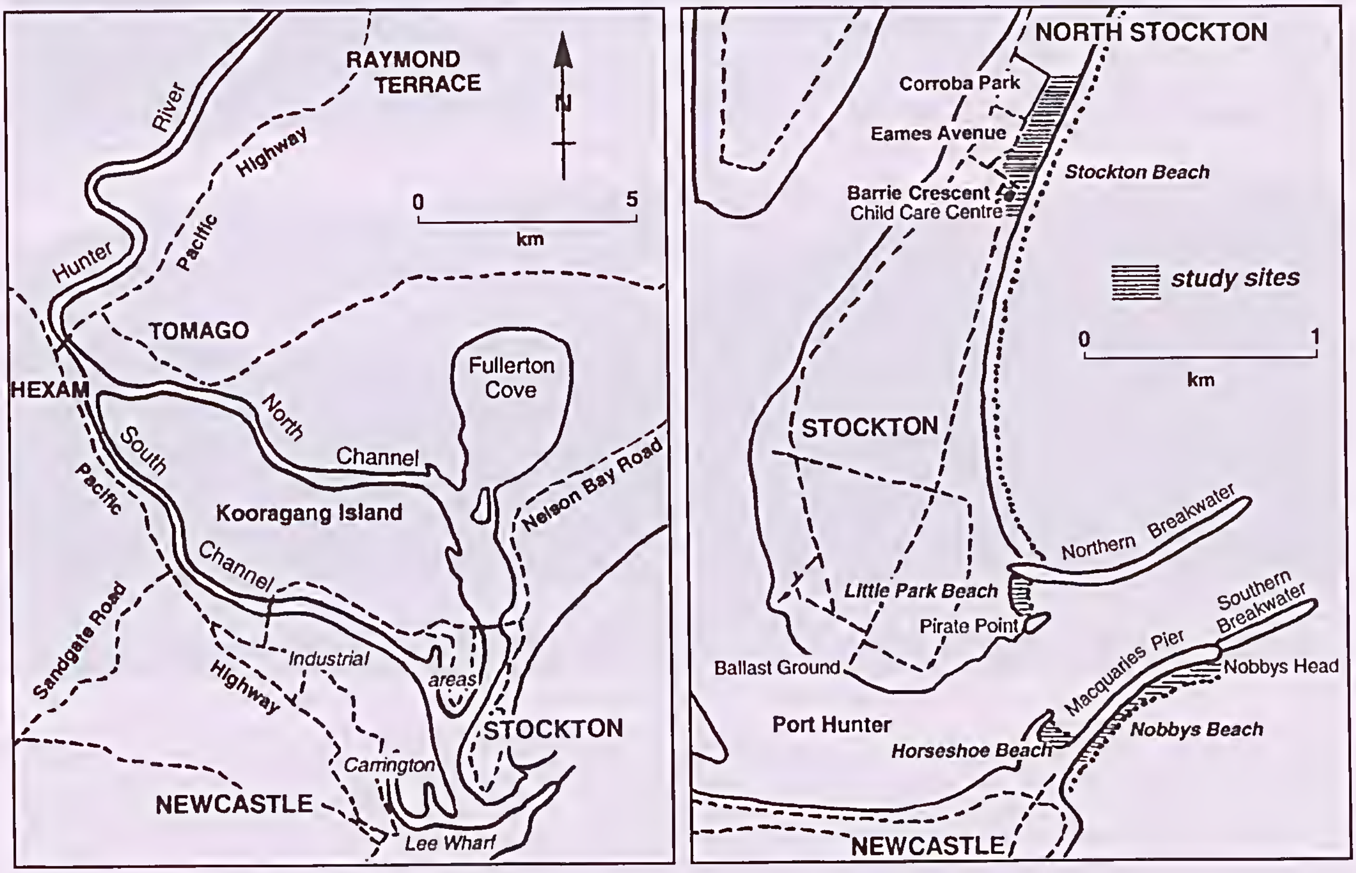

Fig. 1. Location maps of the Port Hunter and Stockton areas.

sericeus also grew down onto the upper beach off Corroba Park, together with a similar grass **Panicum racemosum*, indigenous to the coastal dunes of eastern South America (Heyligers & Lazarides 1997), of which I had seen a patch on the terrace (Fig. 2a).

Developments between 1995 and 2005

During the following years the aspect of the area changed almost beyond recognition. In 1995 two storms in quick succession washed out a 10 m wide slice of the dune terrace, removing the foredune in the seaward zone of **Ammophila arenaria* plantings and a section from the flatter area. Early in 1997 another storm eroded the terrace even further (pers. comm. of a local citizen). Subsequently, the situation more or less stabilised with a scree slope building up against the cliff and limited foredune building on the rim of the cliff, the sand being caught in the low sprawling *Acacia longifolia* subsp. *sophorae* and **Chrysanthemoides monilifera* subsp. *rotundata* shrubs.

At the Eames Avenue section **Panicum racemosum* has become the dominant groundcover, completely eliminating **Ammophila arenaria* which, subject to drought stress and the lack of wind-blown sand, never grew well on the terrace (Fig. 2c and d). **Panicum racemosum* vigorously bounced back after a fire destroyed much of the **Chrysanthemoides monilifera* shrubbery about five years ago. In the early 1990s there was a small area near the road where **Cyperus congestus* was common and over the ensuing years, thanks to its vigorous rhizome growth, it spread as strongly through the roadside section as **Panicum racemosum* had done elsewhere. **Gladiolus gueinzii* is fairly common, but unless seen flowering in spring, it goes unnoticed as its foliage blends in with **Panicum racemosum*. Other species that

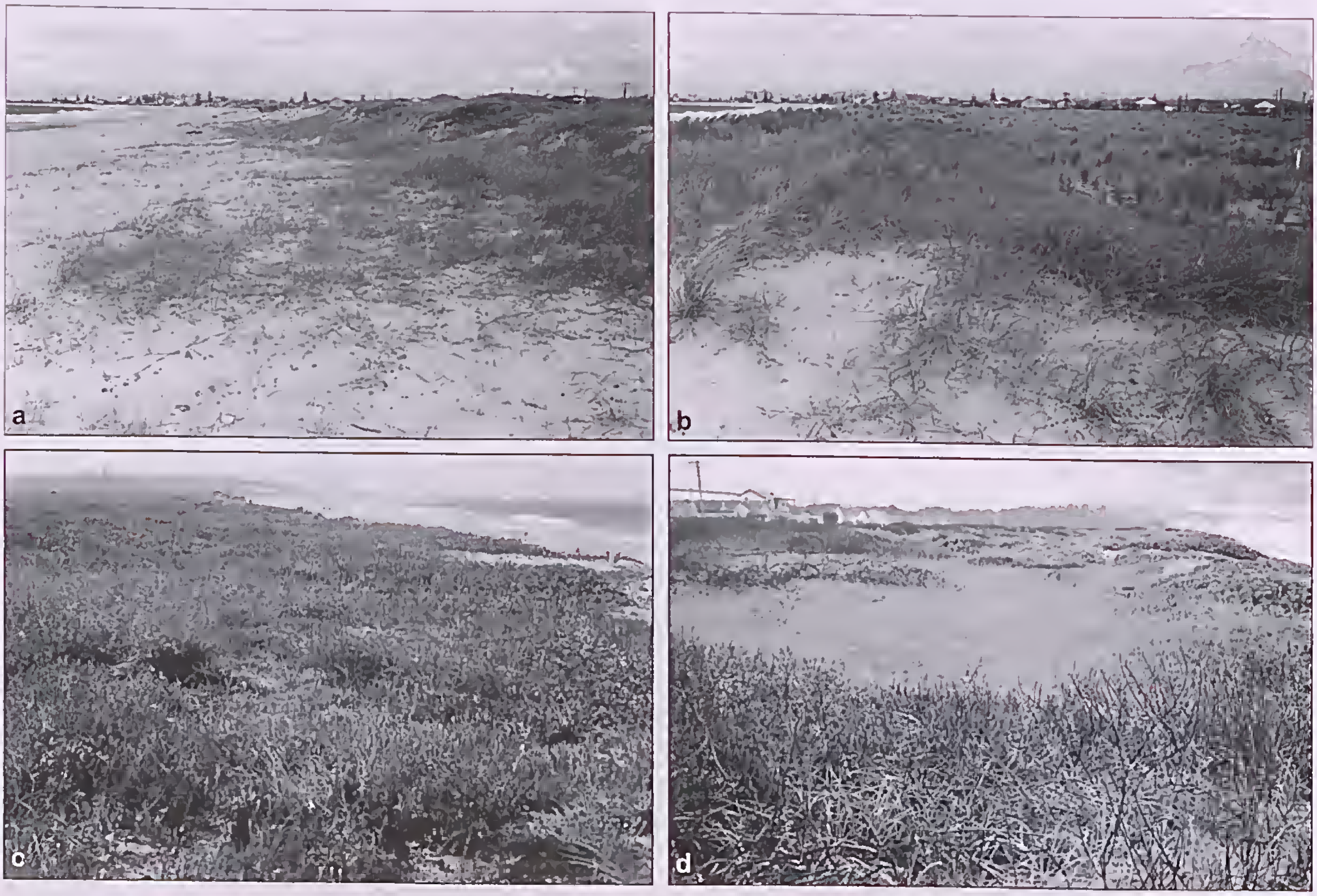

Fig. 2. The Eames Avenue and Corroba Park areas; **a)** the upper beach and scree slope seaward of Corroba Park in March 1994 with **Panicum racemosum* and **Hydrocotyle bonariensis*, both introductions from the Atlantic coast of South America, and occasional *Spinifex sericeus* with **Chrysanthemoides monilifera* subsp. *rotundata* on the terrace; **b)** on the same day a view over the dune terrace of Eames Avenue from the north-eastern corner with **Panicum racemosum* on the low ridge in the foreground and planted **Ammophila arenaria* elsewhere (photos P. J. Fullagar). These pictures were taken before the severe storms of 1995 washed away a wide section of the foreshore; c. and d. are northerly views over the seaward area of the Eames Avenue terrace; **c)** taken in August 1997, shows the heterogeneous vegetation with abundant **Hebenstretia dentata*, much of it dead, and patches of **Chrysanthemoides monilifera* subsp. *rotundata* and **Panicum racemosum*; **d)** taken in April 2003, shows the dominance of **Panicum racemosum*, with **Chrysanthemoides monilifera* subsp. *rotundata* still alive and well on the cliff edge accumulations, but scorched by fire and dead in the foreground as are the shrubs of *Acacia longifolia* subsp. *sophorae* and *Leptospermum laevigatum* which were planted further away from the shore.

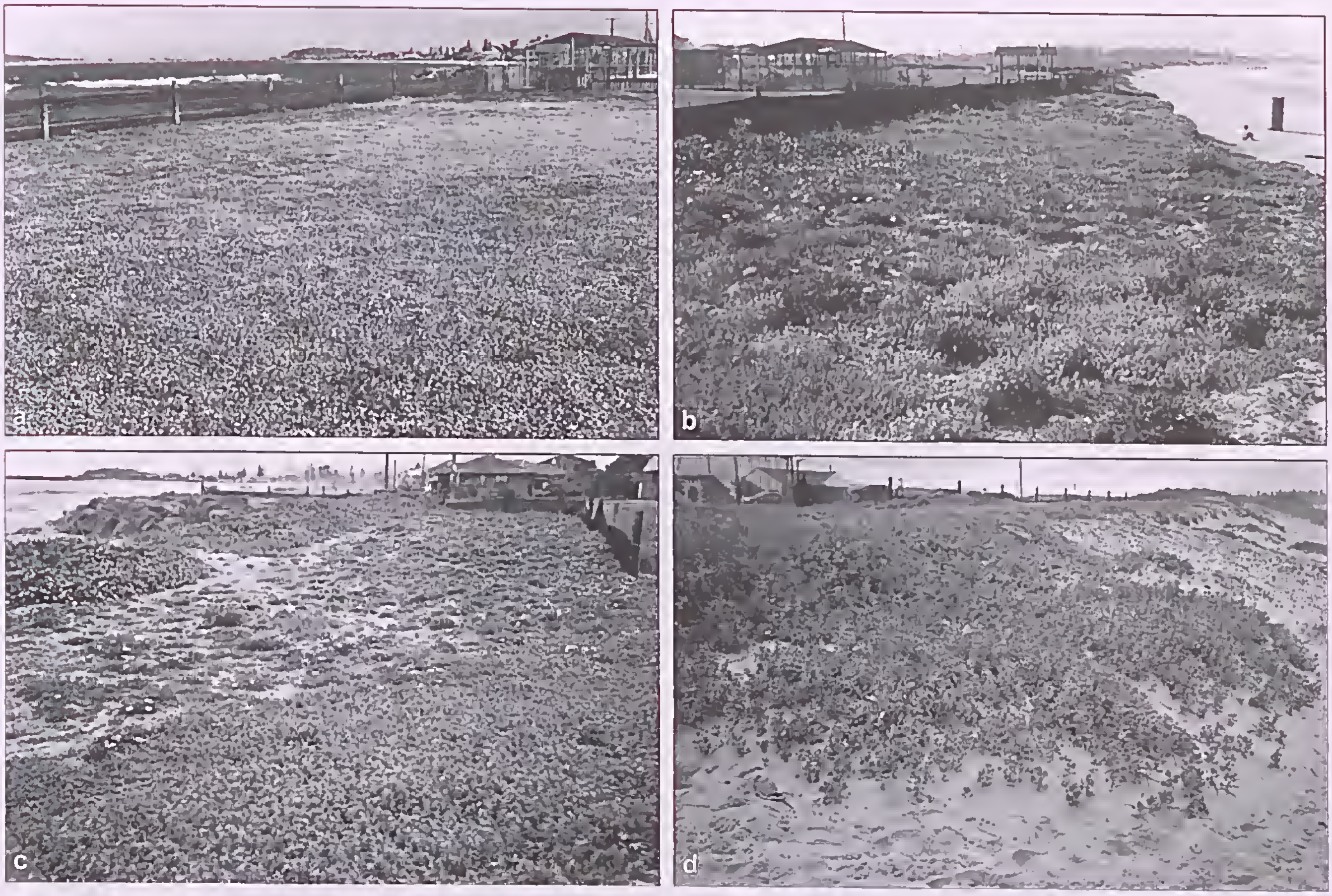

Fig. 3. The Barrie Crescent area; **a**) the 'lawn' around the Child Care Centre in August 1999, when it was overwhelmingly dominated by **Cotula turbinata*; b) a northerly view over the terrace in August 1997, before the windbreak was moved to the school ground fence after much of the terrace had been washed out. In the foreground **Lobularia maritima*, **Gazania rigens* and **Chrysanthemoides monilifera* subsp. *rotundata*, further away a patch dominated by *Cynodon dactylon*; c) a southerly view over the same area in April 2003, with **Galenia pubescens* in the foreground, **Chrysanthemoides monilifera* subsp. *rotundata* along the seaward edge and **Gazania rigens* elsewhere; **d**) the scree slope in April 2003 with, in the foreground, a large patch of **Tetragonia decumbens* with some **Cakile maritima* and much **Hydrocotyle bonariensis* in the middle ground.

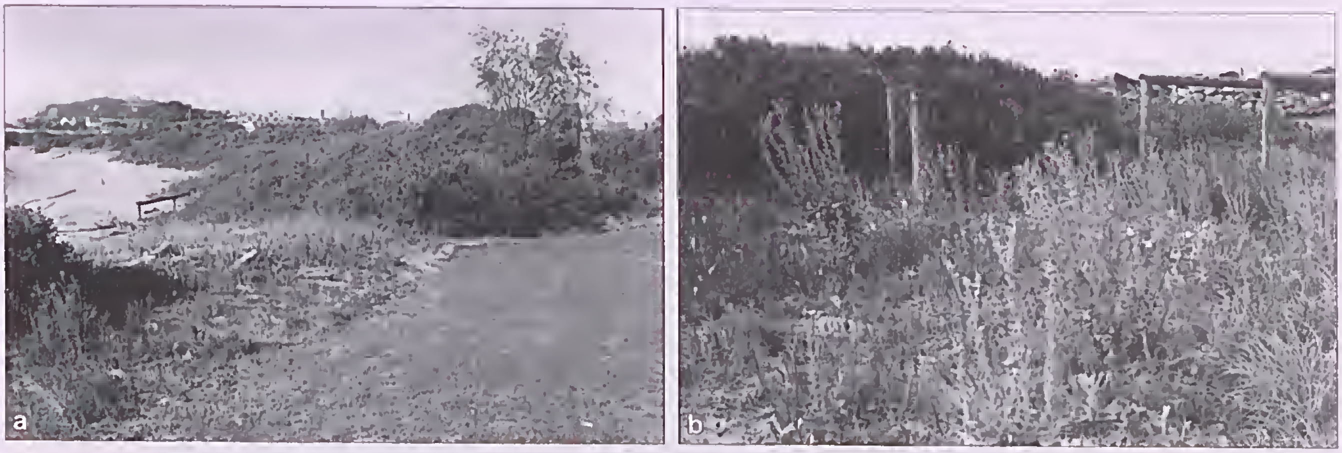

Fig. 4. Little Park Beach; **a**) the beach and terrace shrubbery seen from near the Northern Breakwater in May 1999. *Acacia longifolia* subsp. *sophorae* and **Chrysanthemoides monilifera* subsp. *rotundata* dominate along the seaward edge, while planted *Leptospermum laevigatum* and *Melaleuca armillaris*, together with a few *Casuarina equisetifolia*, form the edge along the Pitt Street Reserve. In the foreground at the right the lawn of the Reserve, at the left a disturbed area with *Spinifex sericeus* and **Heterotheca grandiflora*. At the left in the distance, beyond the base of Pirate Point, Fort Scratchley across the harbour entrance; **b**) **Heterotheca grandiflora* in an open patch along one of the beach access paths with, on the other side, *Acacia longifolia* subsp. *sophorae* and, to the right, **Chrysanthemoides monilifera* subsp. *rotundata*.

Fam.	Species	Status	Source	Eames Avenue	terrace Barrie Cr.	lawn Barrie Cr.	Corroba Park	Little Park	Macquaries Pier	Nobbys Beach	Distribution in NSW	Native distribution of foreign species
Faba	*Acacia longifolia* var. *sophorae*	n, r		4				4	2		coastal	
Myrt	*Leptospermum laevigatum*	n, r		3				3	2		S from Nambucca Heads	
Prot	*Banksia integrifolia*	n, r		2				3	2		coastal, widespread	
Casu	*Casuarina equisetifolia*	i, r		2				2			coastal, N from Laurieton	
Prot	*Banksia serrata*	n, r		2							coastal, widespread	
Loma	*Lomandra longifolia*	n, r		2			2		3		widespread	
Poac	*Ammophila arenaria*	i, r		1	1						coastal S from Newcastle	Europe, Mediterranean
Lami	*Westringia fruticosa*	n, r					2				coastal, also cult.	
Aizo	*Carpobrotus edulis*	i, r	h	1			2		3		CC, SC	S Africa
Myrt	*Melaleuca armillaris*	n, r						2			coastal, heath inland	
Ruta	*Correa alba* var. *alba*	n, r							2		coastal, S from Pt Stephens	
Faba	*Acacia saligna*	i, r							2		mainly coastal	Western Aust.
Faba	*Medicago truncatula**	i	w	4	4	4	4		2	1	widespread	Mediterranean, SW Asia
Poae	*Cynodon dactylon*	n?	b?	4	3	4	3		3		widespread, pasture, lawn	cosmopolitan
Poac	*Panicum racemosum**	i, r?	b	4	3	1	2				(Geelong)	S America
Aste	*Cotula turbinata**	i	b	2	1	4	1				(sandy lawns, swWA)	S Africa
Faba	*Medicago polymorpha**	i	w	4	4	4					widespread	Eur., Mediterr., SW Asia
Aste	*Gazania rigens*	i	h	3	4	4			1		coastal, Sydney-Gosford	S Africa
Bras	*Lobularia maritima*	i	h	2	4	1					coastal, garden escape	Mediterranean
Aste	*Chrysanthemoides monilifera* subsp. *rotundata*	i	b	4	3		4	2	3	2	coastal	S Africa
Onag	*Oenothera drummondii**	i	b	4	4			3	2	3	coastal N from Sydney	N America
Apia	*Hydrocotyle bonariensis*	i	b	4	4			3	3	3	coastal	S America
Cype	*Cyperus congestus**	i	w	4	2						sporadic CC NT NWS	S Africa
Sela	*Hebenstretia dentata**	i	h	4			4	3	3		cult., Newcastle-Nelson Bay	S Africa
Aizo	*Galenia pubescens**	i	b	3	4	2	2	2	2		not common, mine sites	S Africa
Aste	*Senecio pinnatifolius* var. *pinnatifolius**	n		3	3	2	2	2	2		widespread	
Aste	*Ambrosia artemisiifolia*	i	w	2	3	2		3	1		wasteland N from Sydney	N America
Asph	*Trachyandra divaricata*	i	b	3	3	1		1			coast Pt Steph-Wollongong	S Africa
Aizo	*Tetragonia decumbens**	i	b	3	3		2	3	3	2	NC, CC	S Africa
Irid	*Gladiolus gueinzii*	i	b	3	2					2	coast Macleay R-Currarong	S Africa
Aizo	*Carpobrotus glaucescens*	n		2	2		2			2	coastal	
Bras	*Cakile maritima*	i	b	2	2		2	2	2	2	coastal S of Woy Woy	Eur., Mediterr., SW Asia
Onag	*Oenothera mollissima**	i	w	1	2			3	2		N from Sydney, NWS, NWP	S America
Oxal	*Oxalis pes-caprae**	i	h	2	2		2				widespread	S Africa
Oxal	*Oxalis debilis* var. *corymbosa**	i	w	2	2						coastal	S America
Aste	*Ursinia speciosa**	i	h	1	1						coastal at Stockton	S Africa
Aste	*Arctotheca calendula*	i	b	1	1	4		1	2		widespread	S Africa
Alli	*Nothoscordum borbonicum**	i	h	2	1	1					widespread	S America
Comm	*Commelina benghalensis**	i	h	2	1	1			1		NC N from Comboyne	Africa, Asia

Poac	*Stenotaphrum secundatum*	i	h	2	3	1					coastal, lawns	Amer, Africa
Poac	*Spinifex sericeus**	n		3	3		3	4	2	4	coastal	
Poac	*Zoysia micrantha*	n		2	2				1		coastal	
Poac	*Panicum maximum* var. *maximum**	i	p	1	1			3			pasture, roadsides	Africa
Zygo	*Tribulus terrestris*	i	w	1		2					widespread	Europe, Africa, Asia
Poac	*Bromus diandrus**	i	b	1		1		2			widespread	Eur., Mediterr. SW Asia
Bras	*Brassica tournefortii*	i	w	1			2	2	2		widespread	Mediterranean, SW Asia
Faba	*Trifolium repens*	i	p	1				1	1		widespread	Europe, Mediterr., Asia
Faba	*Kennedia rubicunda*	n		1							coastal	
Good	*Scaevola calendulacea*	n		1							coastal	
Aste	*Senecio madagascariensis**	i	w	1							mainly coastal	S Africa
Aste	*Hypochaeris glabra*	i	w	1							widespread	Europe, Mediterranean
Myop	*Myoporum parvifolium**	i	h	1							cult., inland species	
Plan	*Plantago lanceolata*	i	w	1							widespread	Europe, Asia
Verb	*Lantana camara*	i	h	1							coastal	S America
Aspa	*Protasparagus aethiopicus*	i	h	1							coastal N from Sussex Inlet	S Africa
Agav	*Yucca aloifolia*	i	h	1							cult., near Forster	N America
Amar	*Gomphrena celesioides**	i	w	1							widespread	S America
Conv	*Ipomoea cairica*	i	h	1							coastal, NWS, NFWP	pantropic
Bras	*Brassica rapa subsp. sylvestris**	i	h,w	1							widespread	Europe
Aizo	*Lamprantlus multiradiatus*	i	h	1							CC. cult., occ. naturalised	S Africa
Bora	*Heliotropium amplexicaule**	i	h		2	3	2				widespread	S America
Malv	*Malva parviflora**	i	w		1			2			widespread	Mediterranean, SW Asia
Poac	*Bromus catharticus**	i	p		1			2			widespread	S America
Aste	*Heterotheca grandiflora**	i	b		1			3	2		localised on wasteland	N America
Aste	*Conyza parva**	i	w		1			2	1		sandy soils N from Tathra	S America
Sola	*Solanum tuberosum**	i	h		1						cultivated	S America
Conv	*Dichondra repens*	n			2						widespread	
Aste	*Arctotis venusta**	i	h		1						garden escape	S Africa
Poac	*Chloris virgata**	i	p		1						widespread	Asia, Africa, America
Poac	*Sporobolus indicus* var. *capensis**	i	w		2						widespread	Africa
Poac	*Rostraria cristata**	i	w		1						widespread	Mediterranean, SW Asia
Cary	*Polycarpon tetraphyllum*	i	w			2	1				widespread, gardens	Eur., Mediterr., SW Asia
Poac	*Poa annua*	i	w			1	1				widespread	Europe
Cary	*Cerastium glomeratum**	i	w			2		1			widespread	Europe, Mediterranean
Port	*Portulaca oleracea*	n				2			2		widespread	
Faba	*Medicago minima**	i	w			2					widespread	Eur., Mediterr., SW Asia
Port	*Portulaca pilosa*	i	h			1					coastal sand NC	tropics, prob. S America
Aste	*Cotula australis**	n				2					widespread	
Poac	*Lolium perenne**	i	p				2	3			widespread, pasture	W Europe, Mediterr.
Poac	*Ehrharta erecta**	i	w				1	2			widespread	Africa
Aste	*Sonchus oleraceus*	i	w				2	1	1		widespread	Europe, Asia
Sola	*Solanum nigrum*	i	w				2		1		widespread	Eur., Mediterr., SW Asia
Cact	*Opuntia stricta*	i	h				1				widespread, Hunter valley	America
Cras	*Crassula sieberiana*	n					2				widespread	
Poac	*Ehrharta longiflora**	i	w				1				widespread	S Africa
Amar	*Crinum pedunculatum*	n						1	1		coastal N from Jervis Bay	
Poac	*Pennisetum clandestinum*	i	p					2	2		pasture, roadsides etc.	E Africa

Poac	*Lolium loliaceum**	i	p	3	2		uncommon	Mediterranean
Fuma	*Fumaria bastardii**	i	b	1			widespread	Europe
Cary	*Silene nocturna**	i	w	1			waste areas	Mediterranean
Aste	*Bidens pilosa*	i	w	2			widespread	S America
Poac	*Chloris gayana**	i	p	1			pasture	Africa
Poac	*Avena fatua**	i	w	3			widespread	Europe, Asia, Africa
Poly	*Polygonum arenastrum**	i	w		2		widespread	Europe
Bras	*Cakile edentula*	i	b		1	1	coastal	N America
Faba	*Melilotus indicus*	i	w		4		widespread	Mediterr., SW Asia
Aste	*Senecio crassiflorus**	i	b		1		natural. Stockton-Berowra	S America
Sola	*Calibrachoa parviflora**	i	b		2		unco., Newcastle, Boggabri	S America
Conv	*Calystegia soldanella*	n				2	coastal	cosmopolitan

n: native in, but usually not restricted to, the Port Hunter area
i: introduced from overseas or from elsewhere in Australia
r: planted for dune rehabilitation
b: species introduced with ballast
h: species used in horticulture
p: species used for pastures
w: 'weed' (mode of introduction unknown)

* species represented by one or more voucher specimens
4: common; 3: rather or locally common; 2: several; 1: few
Botanical Subdivisions of New South Wales:
NC, CC, SC: North, Central and South Coast
NT: Northern Tablelands NWS and NWP: North Western Slopes and Plains

have appeared from time to time are *Myoporum parvifolium*, **Ursinia speciosa*, **Commelina benghalensis*, **Cotula turbinata* and **Nothoscordum borbonicum*.

At Barrie Crescent the shade cloth fence separating the lawn from the terrace was set back several metres after the repeated heavy erosion of the foreshore. It now links up with the seaward side of the high fence around the Child Care Centre (Fig. 3). The lawn still has an amazing mix of introduced species, even after mowing has recently intensified and resulted in the disappearance of **Portulaca pilosa* and **Trachyandra divaricata*. A particularly memorable occasion was when the **Cotula turbinata* population 'exploded' and covered the lawn with flowers (Fig. 3a). On other occasions this annual species can be absent from the assemblage which, among the predominant *Cynodon dactylon*, includes **Gazania rigens*, *Portulaca oleracea*, **Heliotropium amplexicaule*, **Ambrosia artemisiifolia*, **Medicago truncatula* and **Medicago minima*.

The vegetation on the narrow terrace comprises a mosaic of patches dominated by a single species such as **Gazania rigens*, **Lobelia maritima*, **Ambrosia artemisiifolia*, **Panicum racemosum* or **Stenotaphrum secundatum*, with a row of **Chrysanthemoides monilifera* subsp. *rotundata* shrubs along the southern seaward edge (Fig. 3b and c). Lately, the scree slope has become larger and is locally colonised by a mix of *Spinifex sericeus*, **Panicum racemosum* and some **Cakile maritima* or by large patches of **Tetragonia decumbens* (Fig. 3d). Other species on the terrace include *Cynodon dactylon*, **Trachyandra divaricata*, **Oenothera drummondii* and very succulent *Senecio pinnatifolius* var. *pinnatifolius*. Noteworthy are a sporadic **Ammophila arenaria* tussock and occasionally, **Ursinia speciosa* and **Solanum tuberosum*.

In October 2005 the dune terrace between Corroba Park and the beach was still dominated by **Chrysanthemoides monilifera* subsp. *rotundata*, here as elsewhere now markedly infested by the tip moth **Comostolopis germana*, the result of releases for biological control. However, on a narrow strip along the playing fields **Chrysanthemoides monilifera* subsp. *rotundata* was poisoned and cut and replaced with *Lomandra longifolia* and *Westringia fruticosa*. *Cynodon dactylon* has become common here amid other species such as **Carpobrotus edulis*, **Heliotropium amplexicaule*, **Oxalis pes-caprae*, **Hebenstretia dentata* and **Galenia pubescens*.

Stockton: Little Park Beach

The narrow foredune is dominated by *Spinifex sericeus* with **Hydrocotyle bonariensis* and backed by a shrubbery of *Acacia longifolia* subsp. *sophorae* and **Chrysanthemoides monilifera* subsp. *rotundata* which merges with the taller scrub fringing the Reserve (Fig. 4a). The main species in this restored vegetation are *Melaleuca armillaris* and *Leptospermum laevigatum* with some *Banksia integrifolia* and a few *Casuarina equisetifolia*. **Panicum maximum* var. *maximum* and its cultivar 'Embu' are dominant among an array of grasses along the park fringe.

Open areas in the *Acacia* scrub, especially near the parking area at the foot of the breakwater, carry a large population of **Heterotheca grandiflora*, rather spectacular when in full flower in late summer and autumn (Fig. 4b). Other species common here are **Oenothera drummondii* and **Oenothera mollissima*, **Tetragonia decumbens* and **Hebenstretia dentata*. The low dune front is often eroded by wave action and occasionally large amounts of timber flotsam are thrown onto the beach. The propagule for the one very healthy *Crinum pedunculatum* plant on the foredune would have arrived in a similar way.

Newcastle: the surroundings of Macquaries Pier

The vegetation of Nobbys Beach is dominated by *Spinifex sericeus*, interspersed with **Hydrocotyle bonariensis* and some **Cakile maritima* (Fig. 5c). Patches of **Tetragonia decumbens* and **Oenothera drummondii* are common, and *Carpobrotus glaucescens* and **Gladiolus gueinzii* are present. Many **Chrysanthemoides monilifera* bushes line the southern side of the pier, all of them infested by tip moth. In the 1990s a single **Senecio crassiflorus* plant dominated a large sand accumulation close to Nobbys Head, but in 2003 it was reduced to a few runners and by 2005 it had disappeared (Fig. 5d). Several ruderal species can be found along the pavement of the pier, for instance **Polygonum arenastrum*, but the most notable is **Calibrachoa parviflora*. It also established in the recently landscaped patch around the monument where **Carpobrotus edulis* appears to be the main species used, although flowering **Oenothera drummondii* provides dramatic highlights to this small triangular area (Fig. 5a, b).

At Horseshoe Beach the older planted sections have a 2 m high shrubbery of *Acacia longifolia* subsp. *sophorae*, *Leptospermum laevigatum* and some *Banksia integrifolia*. In the area more recently planted with these species *Spinifex sericeus*, **Cakile maritima*, **Hebenstretia dentata*, **Oenothera drummondii*, **Hydrocotyle bonariensis* and **Carpobrotus edulis* are conspicuous elements in the mostly ruderal species assemblage.

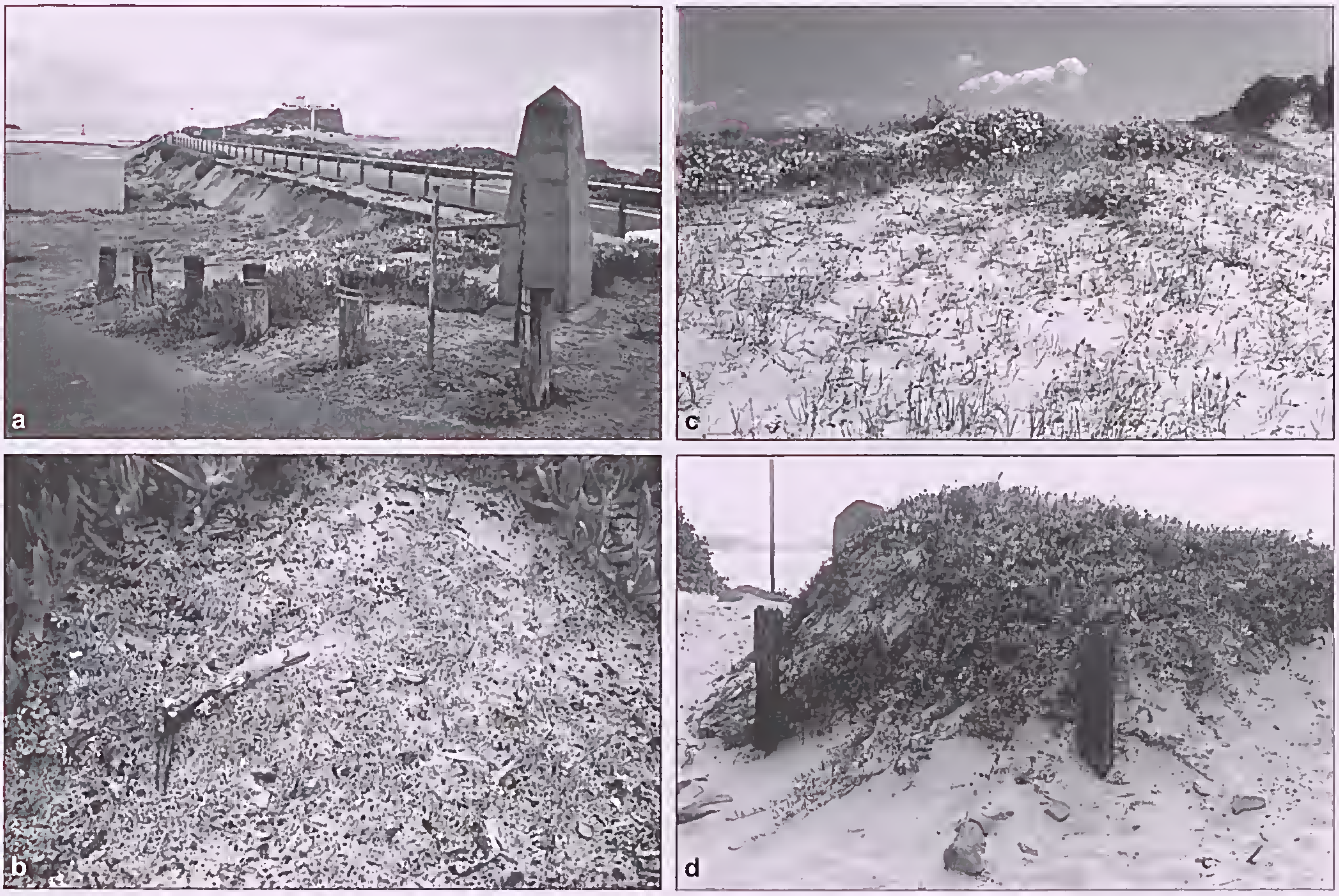

Fig. 5. Macquaries Pier and Nobbys Beach; **a)** the monument at the base of the pier in April 2003, surrounded by **Carpobrotus edulis*, **Oenothera drummondii*, **Arctotheca calendula*, some *Spinifex sericeus* and, near the posts, **Calibrachoa parviflora*; **b)** the open patch of **Calibrachoa parviflora* among the third and fourth post; **c)** a dune on Nobbys Beach sparsely covered by flowering male *Spinifex sericeus* with **Oenothera drummondii* dominant on the crest; **d)** a mound with **Senecio crassiflorus* and **Tetragonia decumbens* along the pier near Nobbys Head in March 1994. This was the only plant of **Senecio crassiflorus* in my study area; it declined in vigour over the years and had disappeared in 2005.

Table 2. Composition of the Stockton/Port Hunter flora

a) Overall composition

21 Native species: 14 coastal, 7 widespread (including 8 planted species of which 3 or 4 are also speading naturally).
78 Introduced species: 75 exotic and 3 Australian but not native in the Port Hunter area;(4 or 5 species used for dune restoration, including 2 Australian and 2 or 3 exotics; 27 species coastal or predominantly coastal in distribution, 51 more widespread)

b) Composition of the exotic flora

22 European species: including 18 extending around the Mediterranean and into south-west Asia;
23 African species not included in previous category, of which 18 South African;
20 American species: of which 14 South American;
10 Species with a wider distribution over two or more continents:

c) Composition of the flora on the Stockton/Port Hunter sites

	Number of species per site			**Percentage of native species (%)**
	native	**introduced**	**total**	
North Stockton				
Corroba Park	7	20	27	26
Eames Avenue	11	48	59	19
Barrie Cr., terrace	6	36	42	14
Barrie Cr., lawn	4	21	25	16
Port Hunter				
Little Park Beach	7	31	38	18
Macquaries Pier	11	28	39	28
Nobbys Beach	3	8	11	27

Table 3. Stockton/Port Hunter foreshore species composition by likely mode of introduction
-numbers are best guesses based on literature and circumstantial evidence.

Volunteer native species - includes *Cynodon dactylon*	13 species
Planted native species	8
Planted introduced species -includes 2 species native elsewhere in Australia	4 or 5
Species introduced with ballast	18
Species used in horticulture, ornamentals, two vegetables, one also used in restoration	21
Species used for pastures	8
Mode of introduction unknown - many are so-called 'camp followers'	29
Total	102

Table 4. Dune vegetation in the 1930s; dune plants reported by Hamilton (1917), Osborn & Robertson (1939) and Pigeon (1940) from the NSW Central and Lower North Coasts. Species arranged roughly according to their abundance.

Strand

**Cakile edentula*

Foredune slope

Festuca littoralis
Spinifex sericeus

Foredune crest and rear

Spinifex sericeus
Festuca littoralis
Scaevola calendulacea
Senecio anacampserotis
Stackhousia spathulata
Chamaesyce psammogeton
Actites megalocarpa
Carpobrotus glaucescens
Isolepis nodosa
Senecio pinnatifolius var. *pinnatifolius*
Pelargonium australe
Hibbertia scandens
Calystegia soldanella
Apium prostratum
Zoysia pungens
Cynodon dactylon
Carex pumila

Dune scrub (also scattered on foredune)

Acacia longifolia var. *sophorae*
Banksia integrifolia
Leptospermum laevigatum
Leucopogon parviflorus
Correa alba
Kennedia rubicunda
Clematis glycinoides
Lomandra longifolia
Oxalis corniculata
Commelina cyanea

Older scrub and dune forest (in addition to most of the above)

Cupaniopsis anacardioides
Monotoca elliptica
Breynia oblongifolia
Myoporum insulare
Angophora costata
Stephania japonica var. *discolor*
Dianella caerulea
Pomax umbellata

Myall Lakes (in addition to list given above)

Banksia serrata
Acmena smithii
Myrsine variabilis
Notelaea longifolia
Clerodendron tomentosum
Dodonaea triquetra
Pandorea pandorana
**Arctotheca populifolia*

Sydney, early introductions (Hamilton 1917)
**Ammophila arenaria*
**Hydrocotyle bonariensis*
**Stenotaphrum americanum*
**Tetragonia decumbens*

Foreign species at Myall Lakes (seen by author in 1994)
**Arctotheca populifolia*
**Cakile maritima*
**Chrysanthemoides monilifera* subsp. *rotundata*
**Eryngium maritimum*
**Gazania rigens*
**Gladiolus gueinzii*

Discussion

The original flora and what is left of it

What would the dune vegetation have been at the time of European settlement? Unfortunately, Robert Brown, who in the spring of 1804 was the first botanist to visit the area, did not provide a description of the local vegetation. At the end of his visit he summarised his collections and from this list it is clear, that he did not find species new to him on the dunes (Vallance *et al.* 2001). More than a century later, Hamilton (1917) described the coastal flora of the Port Jackson district (Sydney harbour) and his lengthy paper is the earliest record of some relevance to the Port Hunter area. Other valuable information about the dune flora before foreign species, especially **Chrysanthemoides monilifera* subsp. *rotundata*, made their mark, are Osborn and Robertson (1939) on the Myall Lakes area, about 75 km north-east of Stockton, and Pidgeon (1940) on the Central Coast of NSW, of which the Hunter River forms the northern boundary. The floristic information from these papers is summarised in Table 4.

In the first half of the twentieth century the foredune vegetation was dominated by *Festuca littoralis* and *Spinifex sericeus*. *Festuca littoralis* was the first species to establish on new sand deposits along the dune while *Spinifex sericeus* stolons descended from the dune crest. *Scaevola calendulacea*, *Senecio anacampserotis*, *Stackhousia spathulata*, *Hibbertia scandens*, *Chamaesyce psammogeton* and *Actites megalocarpa* were often common and the other species occurring on the foredune crest and back slope were apparently not rare either. As far as introduced species are concerned, the only one which was widespread in the 1930s was **Cakile edentula*, a strand-line plant from the east coast of North America. However, Hamilton (1917) reports it from only one beach near Sydney. This species is now rare and has largely been replaced by **Cakile maritima*. Hamilton also found **Tetragonia decumbens* and **Hydrocotyle bonariensis* at a few locations and mentions that **Ammophila arenaria* had been used for dune stabilisation. However, because of unsuitable climatic conditions, establishment was poor and it had almost died out where it had been planted. Osborn and Robertson (1939) found **Arctotheca populifolia*, native to southern Africa, on the drift sands at Myall Lakes, but no other foreign species of any consequence were present in the dune vegetation.

Now, in the early twenty-first century, several of the native species mentioned above are rare and even *Festuca littoralis* is uncommon. It certainly does not fulfil its pioneering role on the dune face any longer. **Hydrocotyle bonariensis* has spread far and wide and is common among the *Spinifex sericeus* vegetation. Of the more recent arrivals **Gladiolus gueinzii* is now widespread, too, but unless in flower, often goes undetected (Heyligers 1998, 1999a). In contrast, and in no small measure due to the sand stabilization activities of the Soil Conservation Service, **Chysanthemoides monilifera* subsp. *rotundata* became common along most of the NSW coast with dire consequences for the native flora (McDonald 1971, Weiss *et al.* 1998). After many eradication campaigns and biological control measures, it still forms a threat due to its ability to establish on the foredunes among *Spinifex sericeus* and young *Acacia longifolia* subsp. *sophorae* vegetation.

In our study area only the dune vegetation along Nobbys Beach is still dominated by *Spinifex sericeus* but it is rather low in species diversity, both native and foreign (Tables 1 and 2). The flora and vegetation on the other sites has been very much modified through human activities. The dunes at Corroba Park are dominated by **Chysanthemoides monilifera* subsp. *rotundata*, but the vegetation of the rehabilitated dunes along Eames Avenue has a rather natural appearance, despite the fact that the species which determine the groundcover physiognomy are predominantly foreign. Native species common in the 1930s, namely *Spinifex sericeus*, *Scaevola calendulacea*, *Carpobrotus glaucescens* and *Kennedia rubicunda*, are now of secondary importance. Only *Senecio pinnatifolius* var. *pinnatifolius*, being an annual, is more common as it tends to thrive on areas disturbed by rehabilitation maintenance.

Arrival and spread of foreign species

Many of the foreign taxa in the Stockton area would have arrived through shipping, either directly from overseas or via other Australian ports. At Port Hunter, ships discharged unwanted ballast at Stockton before loading at the Newcastle wharves. The practice stopped in the twentieth century when solid ballast was replaced by seawater. This had important consequences for aquatic ecosystems, but diminished the chance of introducing terrestrial plants. Unless these had buoyant propagules, they could now only arrive via cargo.

In Stockton, at the southern end of town, there is an area named 'Ballast Ground.' However, the ballast dumps are gone and the area is now a grassed public reserve. Plants that I noticed there along the harbour foreshore, for instance *Tetragonia tetragonioides*, *Atriplex semibaccata*, **Fumaria bastardii*, **Malva parviflora*, **Foeniculum vulgare*, **Verbena bonariensis* and **Senecio madagascariensis*, are all widespread and mostly introduced species. For a number of species the early collection dates in the Newcastle area, e.g. 1908 for **Chrysanthemoides monilifera* subsp. *rotundata*, 1910 for **Senecio crassiflorus* and **Calibrachoa parviflora*, and 1915 and 1923 for **Hebenstretia dentata*, could be indicative of arrival in ballast, but only a note with the **Hebenstretia dentata* specimen from 1923 refers to 'ballast tips.' The early history of **Heterotheca grandiflora*, collected on grain loading wharfs in 1964, is recounted in the Appendix as one of the few, if not the only, example of information which provide an insight into the way a species arrived in the Port Hunter region.

Nearly 20 foreign species on the Stockton dunes are garden escapes. **Gazania rigens*, **Lobularia maritima* and **Hebenstretia dentata* form some of the more conspicuous elements through their large numbers, with **Ipomoea cairica* and **Carpobrotus edulis* providing local highlights. Other species, **Cotula turbinata*, **Ursinia speciosa*, **Commelina benghalensis* and **Nothoscordum borbonicum*, I also suspect of being garden escapes. **Trifolium repens* and a number of grasses, namely the *Chloris* and *Lolium* species as well as **Panicum maximum* and **Pennisetum clandestinum*, were introduced for pasture improvement. The occurrences of the latter in Africa, its introduction into Australia in the earlier decades of the twentieth century and its subsequent cultivation has been described in detail by Cameron (1960).

Most of the remaining foreign species, about 40, have been accidentally introduced, either as contaminants of produce or cargo, on livestock or on people. This could have happened at any port in Australia and internal transport, mainly by ship in the early days of European settlement and later also via roads and railway lines, would have substantially contributed to further dispersal. Almost without exception these are ruderal species: they thrive in disturbed habitats and could be characterised as 'camp followers.' Many of these would have come with the early colonists. As an example, Robert Brown lists 29 introduced species seen in the Port Jackson area in 1802–1804 and mentions species such as **Plantago major*, **Euphorbia peplus*, **Anagallis arvensis*, **Poa annua* and **Lolium perenne* (Britten 1906). Many species labelled as 'weeds' in Table 1 would fall in this category. Hence it is no surprise that such species find an ideal habitat at the restoration sites and much-used beaches at Stockton and, consequently, form the dominant group in the flora of these areas.

Growth habit diversity: is the new foredune vegetation more stable than the old?

Floristically, the vegetation of the North Stockton foredunes appears to be more diverse than the one presumably present in the 1930s (Tables 1 and 4). Would this be important for foredune ecology? Would the present vegetation contribute to greater dune stability? In Table 5 the growth habits of the herbaceous foredune species present in the 1930s are compared with those now present on the North Stockton dune terrace and frontal slope. For the latter group only the 26 species on the Eames Avenue and Barrie Crescent sites which had an abundance score of 2 or higher on at least two of the sites are used. The two groups have only five native species in common, three of which are grasses.

Table 5. Comparison between the functional groups of herbaceous species in the dune vegetation of the 1930s (strand and foredune species in Table 4) and in the vegetation of the three rehabilitated sites at Eames Avenue and Barrie Crescent (species with an abundance score of 2 or higher on at least two of the sites).

	1930s vegetation		**Present vegetation**		**Species in common**
	native	foreign	native	foreign	
Total number of species	16	1	5	21	
Annual species	1	0	1	7	*Senecio pinnatifolius* var. *pinnatifolius*
with bushy habit[1]	0	1	0	1	
Perennial species	15	0	4	14	
with spreading habit	9	0	4	6	*Carpobrotus glaucescens*
graminoids	3	0	3	3[5]	*Spinifex sericeus, Zoysia micrantha, Cynodon dactylon*
with bushy habit[2]	5	0	0	3	
with storage organs[3]	0	0	0	6	
others[4]	1	0	0	5	

[1] the two **Cakile* species.

[2] include species such as **Stackhousia spathulata*, **Actites megalocarpa* and **Oenothera drummondii.*

[3] include **Cyperus conglomeratus*, **Trachyandra divaricata* and the **Oxalis* species; some of those species are also included in the previous groups.

[4] for instance *Senecio pinnatifolius*, **Gazania rigens* and **Hebenstretia dentata*.

[5] **Panicum racemosum*, **Cyperus congestus* and **Stenotaphrum secundatum*.

A major difference between the 1930s flora and the present one is the large number of annuals now present, mostly foreign species, e.g. **Medicago* spp., **Cotula turbinata*, **Lobularia maritima* and **Arctotheca calendula*. However, the number of perennials is rather similar, with the exception of species with underground storage organs, which were lacking in the 1930s vegetation. Interestingly, the total number of spreading species, whether they are rhizomatous or sprawl over the surface, is almost the same, but there is now a higher proportion of graminoids compared with other herbaceous species. This is an important difference because the graminoids (in this case five grasses and **Cyperus congestus*), fulfil a major ecological function in the vegetation by trapping windblown sand, a function strengthened by the subsequent establishment of shrubs which are initially decumbent (namely *Acacia longifolia* subsp. *sophorae* and, in the present vegetation, **Chrysanthemum monilifera* subsp. *rotundata*). These growth-forms are well suited to catch windblown sand and would be major contributors to building larger, more stable dunes. Bushy species, be they native or foreign, are also sandcatchers and, if present in sufficient numbers, could be equally effective in stabilisation. Hence, when one compares the ecological functioning of the 1930s vegetation with that of the present vegetation, it would appear that, due to presence of more graminoids and the fact that **Panicum racemosum* produces a denser sward than *Spinifex sericeus*, the present vegetation is more effective in sand-catching and dune stabilisation than the vegetation in the 1930s would have been.

In view of this conclusion, is the present dune terrace at North Stockton less liable to erosion? Unfortunately, along this stretch of the coast, little sand is available because of breakwaters at the entrance to Port Hunter. Sand carried by northerly longshore currents is diverted too far out to sea, and is not be returned to the beach north of the breakwaters. The storm attacks experienced in 1995 and 1997 resulted in dramatic erosion of the existing foredune. In view of the increasing influence of climate change, e.g. a rise in sea level and more extreme weather events, there is no indication that the present terrace, notwithstanding the increased density of the rhizomatous species **Panicum racemosum* and **Cyperus congestus,* and a sprawling shrubby vegetation along the erest, will endure such attacks any better than in the 1990s.

Conclusion

The exploration of the flora around the sandy foreshores at Port Hunter has revealed the presence of a large number of foreign plant species. Since the first coal exports in the 1850s the Newcastle wharves and ballast ground at Stockton became points of entry for foreign species, either directly, or via stopovers at other Australian ports. Some of these, **Panicum racemosum*, **Tetragonia decumbens*, **Ursinia speciosa*, **Hebenstretia dentata* and until recently, **Heterotheca grandiflora* remained restricted to the Newcastle region, while others, **Chrysanthemum monilifera* subsp. *rotundata*, **Hydrocotyle bonariensis*, **Gladiolus gueinzii* and **Oenothera drummondii*, spread further afield, but only colonised their preferred coastal habitat. Many more species spread far and wide, their port of introduction no longer recognisable.

Foreign species have made their mark on the local vegetation to varying degrees. At Nobbys Beach the general aspect of the dune along the pier is still determined by *Spinifex sericeus*, but closer look will reveal the widespread occurrence of **Hydrocotyle bonariensis* among the grass, while apart from *Carpobrotus glaucescens*, introduced species such as **Tetragonia decumbens* and **Oenothera drummondii* occur on some low crests. But on the whole, the dune vegetation is similar to that of the other dunes in the region. In contrast, the North Stockton dune terrace is dominated by foreign species. **Panicum racemosum* and **Cyperus congestus* dominate the ground cover at Eames Avenue, **Gazania rigens*, **Stenotaphrum secundatum* and **Galenia pubescens* do so at Barrie Crescent, while **Chrysanthemoides monilifera* subsp. *rotundata* is still conspicuous.

I recorded 51 species in the Eames Avenue section (disregarding planted species), and 44 species at Barrie Crescent. In both cases, only 6 are native to Australia (*Spinifex sericeus*, *Carpobrotus glaucescens* and *Senecio pinnatifolius* var. *pinnatifolius* are the more important), while a seventh, *Cynodon dactylon*, is regarded as a cosmopolitan species. The foreign species have come from the four corners of the globe. If there ever was a multinational thriving vegetation assemblage, this one surely must have pride of place!

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Appendix 1 Comments on 15 notable introduced species of the Port Hunter area

(arranged in family order of Harden (1990–1993, 2002).

1**Galenia pubescens* (Aizoaceae; Fig. 3c)

This low, sprawling species from southern Africa has a widespread but scattered distribution in southern Australia. Kloot (1986) reports it from ballast dumps at Port Germein, South Australia, in 1916. In NSW it is 'not very common but often locally abundant around mining areas' (Jacobs & Highet 1990). There is probably a connection here as ore mined at Broken Hill, in far western NSW, is processed at Port Pirie, close to Port Germein. Hence, **Galenia pubescens* could have travelled inland via the railway line. Similarly, it is also common along roads and in disturbed areas in the lower Hunter Valley with its numerous coal mines.

In the early 1940s Mort (1949) found **Galenia pubescens* on the Central Coast and lists it as a 'strand species' possibly useful for dune restoration. In Victoria, Walsh (1996) reports it to be 'common in coastal areas in the Melbourne and Geelong areas, growing on beach sand and the hinterland, occasional in dryish, often somewhat saline areas in the north and north-west, scattered on open wasteland (railyards, roadsides etc.) elsewhere.' In the Flora of South Australia **Galenia pubescens* is mentioned as occurring 'especially near the sea' from the Adelaide area to the Eyre Peninsula as well as near the Flinders Ranges (Jessop & Toelken 1986). In Western Australia **Galenia pubescens* has been found in disturbed areas in Perth and Bunbury and also in Kalgoorlie (Hussey *et al.* 2007). These distribution patterns point to introductions in contaminated ballast and subsequent transportation inland via railway lines and roads. Adaptable to dry and somewhat saline conditions, **Galenia pubescens* occurs among the rocks of Macquaries Pier, and in patches at North Stockton, where it also climbs the windbreak fence.

2**Tetragonia decumbens* (Aizoaceae; Fig. 3d)

The history of this species as well as that of **Trachyandra divaricata* has been analysed by Heyligers (2002) and only a few aspects relevant in the context of this paper will be mentioned. The first Australian specimen of **Tetragonia decumbens*, a species native to South Africa, was collected in 1908 on Coode Island, the ballast ground for Port Melbourne (Tovey 1911). It 'covered the ground in a thick mass, the branching stems trailing out in all directions.' However, it has not persisted on the island, nor is there any evidence that it spread along the shores of Port Phillip Bay.

Early records of **Tetragonia decumbens* in NSW are from the Sydney area where it was collected at Maroubra in 1917 and Camp Cove, on the southern shore of Port Jackson, in 1919 but at both locations the species has disappeared (Heyligers 1999b). In 1947 Mort collected **Tetragonia decumbens* on Stockton Beach and lists it as a mat-forming plant possibly useful for dune restoration. I do not know whether it has been used for that purpose, but it is rather common at Stockton where, like **Galenia pubescens*, it may cover sand-stilling fences, as well as on the dunes at Nobbys Beach, where individual plants accumulate broad mounds in the *Spinifex sericeus* vegetation. It also occurs near Anna Bay, at the north-east end of Stockton Beach.

3 **Oenothera drummondii* (Onagraceae; Fig. 5c)

In 1929 the first specimen of **Oenothera drummondii* in NSW was collected at Waratah, now a suburb of Newcastle, followed by a second specimen from Newcastle in 1940 and a third from Coffs Harbour in 1941. At that time this species was already widespread along the beaches and islands of southern Queensland where, between 1924 and 1933, it had been collected five times in the Moreton Bay area and once, in 1937, at Maroochydore on the Sunshine Coast.

After their coastal survey of NSW in the mid to late 1940s, Mort and Hewitt (1953) commented that the distribution of **Oenothera drummondii* was limited, but that it was plentiful in the Coffs Harbour district 'where its lemon yellow flowers produce a very attractive display in the late spring and summer months. Its use as a sand stabilising species is very limited, but its free-seeding habit assists, together with the other species on the sand, to produce a dense growth which is quite an effective barrier to all but the severest gales.'

At Nelson Bay *Oenothera drummondii was collected in 1961 but not until 1966 at Stockton. It is not listed by Bodkin (1986) among the eleven Oenothera species available at nurseries. In Western Australia *Oenothera drummondii is common on the dunes near Perth, which Smith (1985) assumes is due to its introduction as a garden plant. Nevertheless, the early occurrences in Western Australia, NSW and Queensland point to introduction through shipping, although its apparently late appearance at Stockton is puzzling.

4 **Heterotheca grandiflora* (Asteraceae; Figs. 4b and 6)

This striking species is native to the south-western United States of America and northern Mexico. Specimens and accompanying correspondence at NSW indicate that the first colonies of **Heterotheca grandiflora* in Australia were discovered in 1964 at Carrington and Lee Wharf on the southern shore of Port Hunter. A. J. Beck, the East Maitland Agronomist, in a letter dated 20 April 1966, described these occurrences as follows: 'The colony at Newcastle is located on a sandy footpath directly opposite the rock phosphate unloading equipment, which is situated at No.5 Lee wharf. The plants ranged from seedlings to mature plants, tallest of which is included in the specimens to be sent to you. The colony population consisted of some 360 plants and extended over an area of some 40 to 50 yards. At Carrington a smaller colony was located on some waste land behind the Wheat Terminal Wharf and directly adjacent to the silos. The plants here consisted of 20 in number ranging from seedlings to mature plants 4 feet high. The more vigorous growth of these plants is probably due to a better environment.'

Later **Heterotheca grandiflora* was found to be common at the grain terminal on Kooragang Island. The identity was checked by H. K. Sharsmith, a Californian taxonomist, who on 29 March 1966, after confirming the identification, wrote 'This species is a native in California and, although weedy from the standpoint of favoring disturbed waste ground, it is not an economically significant weed and does not invade agricultural lands.' She also mentions its introduction in Hawaii before 1920 and that it was reported to be a noxious weed of pineapple fields.

A related species, found in the south-eastern United States of America, *Heterotheca latifolia*, was used for experiments to determine the ecological consequences of achene dimorphism (Venable and Levin 1985). The ray and disc flowers of this species, like those of *Heterotheca grandiflora* and the other species in the section *Heterotheca*, produce markedly different achenes. The results of one of the experiments showed that wind dispersal was more effective for disc achenes, which have a well-developed pappus of capillary bristles, than for ray achenes, which lack a pappus. *Heterotheca latifolia*, just like **Heterotheca grandiflora*, is an annual and grows on sandy or rocky ground, on disturbed soils, in pastures and on wasteland. Since the 1930s it has enlarged its territory, frequently following railways and roads.

Attempts were made to eradicate **Heterotheca grandiflora* when it first appeared in 1966, but were apparently not successful. The occurrence at Raymond Terrace was first documented by a collection made in 1976. Subsequently, **Heterotheca grandiflora* became widespread between Hexham and Raymond Terrace in pastures and wasteland (Porteners 1992). It was collected in 1993 along the Tomago-Nelson Bay Road and a year later I found it at Stockton. Although not uncommon in the area north of Port Hunter, it would appear that, as observed in California, these occurrences are not economically important. Recent occurrences in northern NSW and south-eastern Queensland would indicate that spread to other areas, just like the expansion of **Heterotheca latifolia*, has already started.

5 **Cotula turbinata* (Asteraceae; Figs. 3a, 7a and 7b)

Until found at Stockton, **Cotula turbinata*, a species native to South Africa, was only known to occur in Australia in the south-west of Western Australia, at mostly coastal locations between Perth and Albany. Marchant *et al.* (1987) describe it as a 'weed of sandy soils, particularly in lawns.' This applies to the conditions at Stockton, where I have found it at Barrie Crescent and Eames Avenue, in the park along the foreshore and on the small oval in the centre of Beeston Street, off Eames Avenue. It is possible that we are dealing here with two independent introductions, one to the the west coast and another one to the east coast of Australia. In New Zealand Kirk (1896) found this species on a ballast heap near Wellington, dumped by a vessel arriving from Buenos Ayres, South America, together with **Calibrachoa parviflora* and many other species. Apparently, it has a way of getting around!

The inflated peduncle under the flowerhead makes **Cotula turbinata* stand apart from other *Cotula* species and it may have a wider distribution along the NSW Central Coast than has been recognised. *Cotula australis* grew among the* *Cotula turbinata* plants. This native species, often common in open grassy situations, is found throughout temperate Australia and has spread far and wide overseas: not only does it occur in New Zealand and South Africa, but Jörgensen & Ouren (1969) also mention Sri Lanka, the Canary Islands and the Pacific States of the United States of America, while Jörgensen also found it on the grain import quay in Oslo, Norway, where it is presumed to have come in with Australian wheat. **Cotula coronopifolia* is another species that has spread far and wide. Its status in Australia is unclear; it could have arrived here with the First Fleet from South Africa, where it is regarded as a native species. However, Brown mentions *?Cotula coronopifolia* in his list of introduced species at Port Jackson (Britton 1906). It is not clear whether Brown queried the introduced status or that he was not sure of the identification, as he collected quite a few specimens from the local area. Whatever the case, the species has now spread to the far corners of the globe (Heyligers 1995).

6 **Senecio crassiflorus* (Asteraceae; Fig. 5d)

This species is a dune plant, native to the Atlantic coast of South America where it occurs in the company of **Panicum racemosum*, **Hydrocotyle bonariensis* and **Cakile maritima*, among others (Eskuche 1973, Costa *et al.* 1996). In Australia **Senecio crassiflorus* is 'cultivated as an ornamental, sometimes naturalised in coastal districts from Stockton to Berowra district' (Harden 1992a). However, Mort and Hewitt (1952) assume that 'due to the fact that it appears to be localised in the Newcastle district it is thought that it may have been brought in with ballast from South America in the sailing days. This plant is now naturalised in Australia and has spread fairly extensively from Belmont to Stockton, where it was recorded as early as 1910.' There are only a few collections of this species at NSW; the earliest being one from Newcastle made in 1912. In 1918 **Senecio crassiflorus* was collected at Swansea, followed by one at Stockton in 1925. The occurrence in the Berowra district appears to be based on a 1924 collection made between Cowan and Berowra on the west side of Kuringai Chase, well away from the coast and could have been a garden escape.

**Senecio crassiflorus* was tested by the Soil Conservation Service for dune restoration at The Entrance North with the result that 'this plant will prove invaluable for vital exposed areas, particularly in close proximity to the beach, where a small quantity of sand is collected from time to time. This has the effect of a light topdressing; however, with six inches accretion of sand or more the plant is often completely inundated and destroyed' (Mort & Hewitt 1952). As it had been known in the Newcastle district for about 40 years and had not spread beyond other beach areas, Mort and Hewitt advocated 'its encouragement on areas of coastal sand drift ... particularly in situations of extreme exposure and in close proximity of the beach.' Apparently, this advice has not been taken to heart, although the label of a collection at CANB from Sawtell Beach (south of Coffs Harbour) made in 1967 states that it was planted for the prevention of soil erosion. There is no other evidence of occurrences outside the area originally outlined by Mort and Hewitt and the only plant seen at Macquaries Pier is no longer present.

7 **Ursinia speciosa* (Asteraceae; Fig. 7 c and d)

There are only two collections of this South African species at NSW; one made in 1967 at Fullerton Cove north of Stockton, the other my collection from North Stockton made in 1996. At Fullerton Cove it was rare and found on a sandy knob over about 1.5 ha. The collector, O. Wykes, added to the label that this occurrence 'appeared to be the only area of infestation [sic!] in the Port Stephens Shire.' After receiving the Fullerton Cove specimens K. Mair, Director of the Sydney Royal Botanic Gardens, in providing the identification, writes 'This species was recorded by Ewart in Flora of Victoria 1931 in a list of plants which "occasionally appear spasmodically, mostly as garden escapes". It has, to my knowledge, not been recorded as naturalized in other States.' He then refers to Mort (1949) where an '*Ursinia* sp.' is mentioned as possibly suitable for planting on windward aspects of foredunes on the Central Coast. On this basis Mair surmises that the Fullerton Cove occurrence could either have originated through sand stabilisation work or from windblown seed and advises the District Agronomist to watch this species 'for indications of spreading to native bushland.' However, the occurrences of **Ursinia speciosa* have remained spasmodic and certainly have not lead to further 'infestations.'

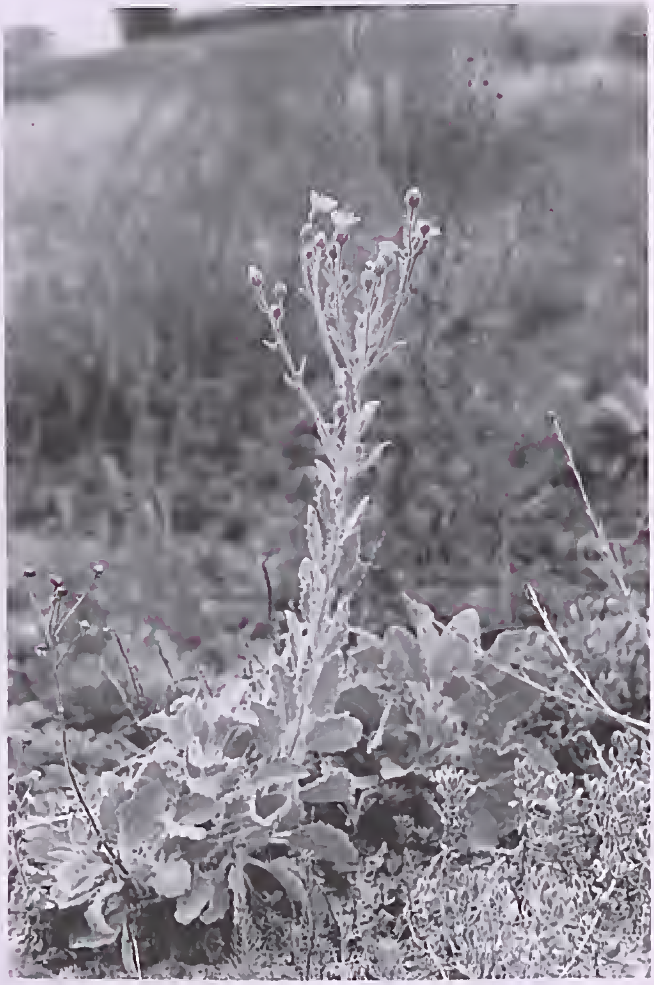

Fig. 6.* *Heterotheca grandiflora* at Little Park Beach in September 2005 just coming into flower. It is a biennial species that 'overwinters' in the rosette stage and flowers in spring and summer. Previous season's dead plants are out of focus in the background.

It is of interest to go to the earliest known occurrence of this species in Victoria. In 1908 and 1909 Tovey (1911) found **Ursinia speciosa* on Coode Island, on the south bank of the Yarra River near its mouth, and was sure that it had come in with ballast dumped on that particular side of the island. Tovey, a Senior Assistant at the National Herbarium of Victoria, writes '... is only known in this State from this locality. It was growing in great profusion ... I brought away some of the young plants of the Ursinia [no italics], and planted them in my garden: but they seeded so freely and spread so rapidly that I had to pull them up, or they would have taken possession of the garden.' The species is not mentioned by Walsh and Entwisle (1999) and, Tovey's fear notwithstanding, one may assume that it did not become naturalised in Victoria. However, Hussey *et al.* (2007) report that in south-western Western Australia **Ursinia speciosa* 'is a garden escape that has naturalised in peppermint woodland at Hamelin Bay.' No *Ursinia* species are listed in Bodkin (1986), and hence one may assume are not available from plant nurseries.

The short-lived occurrence of **Ursinia speciosa* at North Stockton does not stack up with assumptions about an invading exotic nor about suitability for dune stabilisation. We can only wonder where the seeds of the small Stockton population came from. As I have been informed that it still is present on a few hectares near Fullerton Cove, it could have come from that location.

8 **Chrysanthemoides monilifera* subsp. *rotundata* (Asteraceae)

This subspecies of **Chrysanthemoides monilifera* is restricted to littoral habitats in the south-east of southern Africa. In eastern Australia its occurrences are also predominantly coastal, but it is also known from some inland locations where it was used for sand drift control (Weiss *et al.* 1998). The first herbarium specimen of **Chrysanthemoides monilifera* subsp. *rotundata* was collected in June 1908 at Stockton (Gray 1976). Cooney *et al.* (1982) mention that it had become particularly well established in the Stockton area by the early decades of the twentieth century and could have been introduced with ballast dumped on the north bank of the Hunter River.

In the early 1950s its 'naturalised' distribution was still limited to the Newcastle area, where it was proclaimed a noxious weed (Mort & Hewitt 1953). However, at that time the subspecies was already used in other locations for dune reclamation by the NSW Soil Conservation Service because of its excellent sand-stilling and sand-binding qualities. After its disastrous influence on the native vegetation was recognised, this practice was stopped and replaced by control programs.

After its release in 1989 the bitou tip moth has become established at many locations along the NSW coast. Especially where plants are directly exposed to coastal winds, the moth can cause significant reductions in flower and fruit production (Weiss *et al.* 1998). But on the

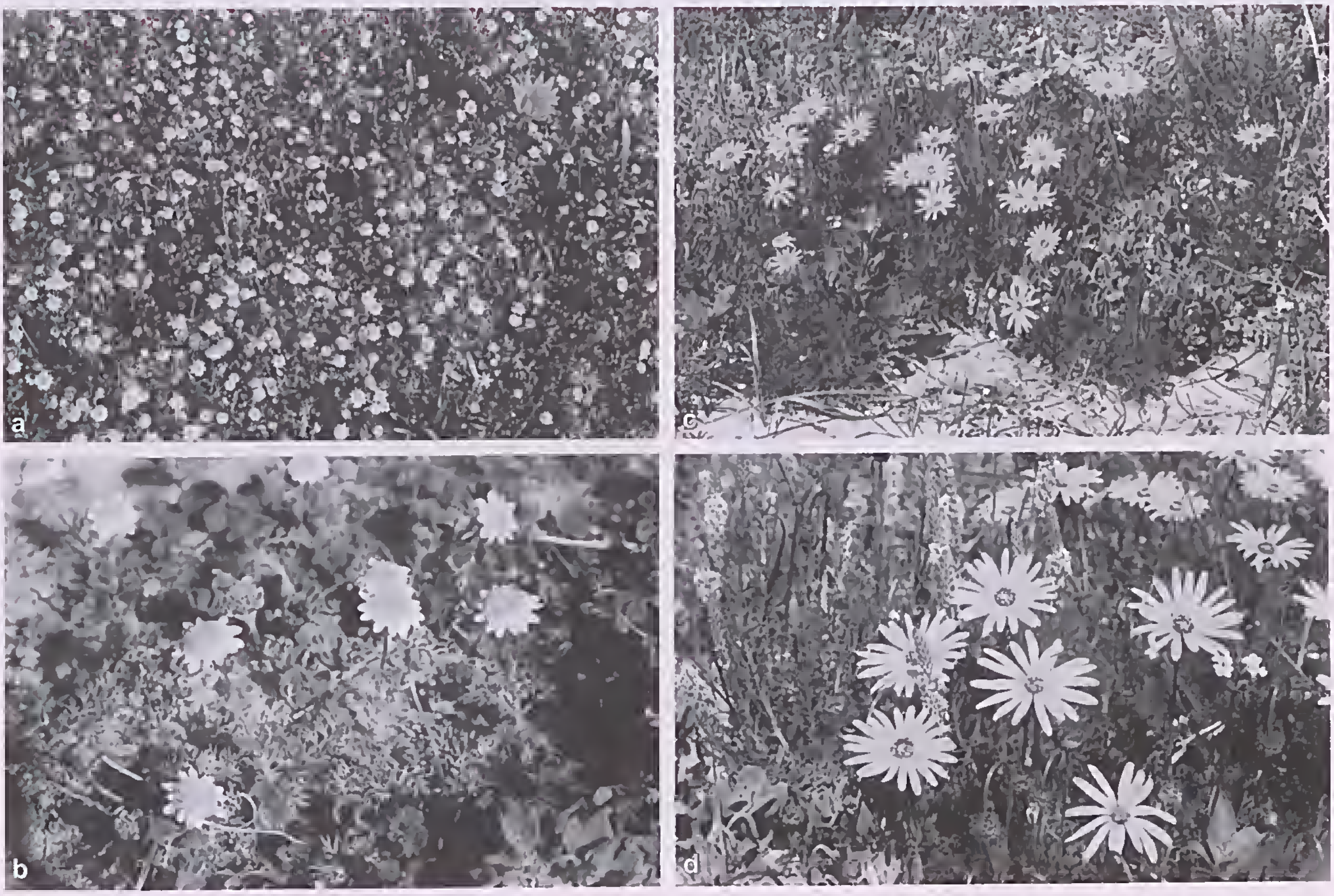

Fig. 7. **Cotula turbinata* and **Ursinia speciosa* at Barrie Crescent; **a)** a closer view of the **Cotula turbinata* 'lawn' shown in Fig. 3a; **b)** **Cotula turbinata* in flower and fruit in August 1997; note the funnel-shaped swelling of the peduncle under the fruiting head at left; **c)** and **d.** **Ursinia speciosa* among **Hebenstretia dentata* and **Tetragonia decumbens*; on **d)** towards the right a fruiting head showing the scarious pappus scales.

foreshores at Stockton this is not severe enough to keep regeneration of **Chrysanthemoides monilifera* subsp. *rotundata* in check and at Eames Avenue hand-pulling of young plants is still necessary.

9 **Solanum tuberosum* (Solanaceae; Fig. 8d)

In 2003 I found about twenty plants of a *Solanum* species in a grassy area close to the beach cliff at Barries Crescent. B. Lepschi (at CANB) provisionally identified them as **Solanum tuberosum* and D. Symon who confirmed the identification. He said, however, that '…the style is markedly longer and the calyx lobes shorter than any specimens we [i.e. at the State Herbarium of South Australia] have.' Despite trying to dig up some plants, I could not find tubers, although these may have remained out of reach among the dense roots of **Stenothaphrum secundatum* and *Cynodon dactylon*.

10 **Calibrachoa parviflora* (Solanaceae; Fig. 5b)

**Calibrachoa parviflora*, native of South America, is an 'uncommon weed, chiefly from Newcastle and Boggabri districts, also doubtfully naturalized in the Narrabri area' (Conn 1992). The earliest specimen at NSW was collected in November 1910 at Stockton Beach, the next two specimens in January 1941, one from the 'Newcastle District,' the other from Nobbys Head military camp. This points to introduction in ballast, an assumption supported by evidence from Kirk (1896), who found it near Wellington, New Zealand, on a heap of ballast dumped by a ship coming from South America. There were no further records from the Newcastle area until 1999 when I found a plant growing next to the pavement of Macquaries Pier. The specimen from the Boggabri district, the first of the four inland collections, dates from 1948. Disturbed grassland, a lawn of Buffalo Grass and riparian vegetation are mentioned on the labels of the other specimens, the latest one collected at Myambat on the Central Western Slopes in 1998.

11 **Hebenstretia dentata* (Selaginaceae; Fig. 8 a and b)

Harden (1992b) gives the status of this species, native to South Africa, as follows: 'Cultivated as an ornamental, occasionally naturalized in the Newcastle to Nelson Bay district.' Several labels of the nine herbarium records on which the naturalised distribution is based mention that the plants were found in disturbed areas, with one collection, made in 1970, coming from Stockton where it was 'frequent on disturbed, flattened sandy area behind beach.' This sandy area could well have been the foreshore at Eames Avenue. The earliest collection, also at Stockton, was made in 1915, well before any dune restoration work was mooted. The most interesting information was provided by W. M. Steinbeck with a specimen collected in June 1923: 'This plant grows freely on the foreshores at Stockton and it seems to be spreading back from ballast tips and is probably introduced.' **Hebenstretia dentata* is, or has been, sold by plant nurseries, as it is listed by Bodkin (1986) and I think it likely that this species was taken into cultivation for its ornamental qualities after its accidental arrival at Port Hunter. Mort (1949) listed *Hebenstretia dentata* in his suggestions for plants that may be useful in dune stabilisation.

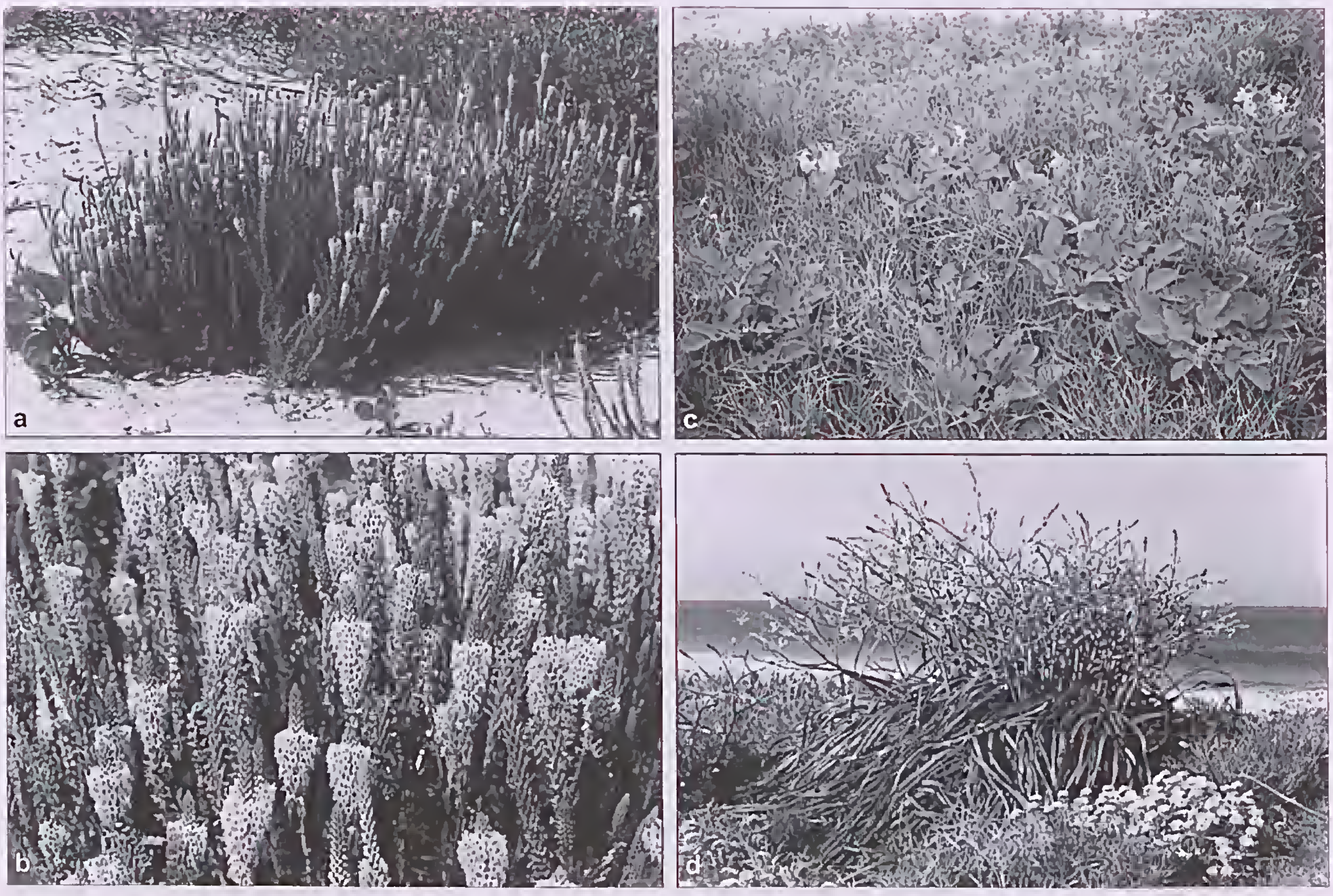

Fig. 8. a) **Hebenstretia dentata* on an open patch in the **Chrysanthemoides monilifera* subsp. *rotundata* vegetation near Corroba Park in August 1997; **b)** a close-up showing how the tightly closed **Hebenstretia dentata* buds almost literally burst into flower; **c)** the puzzling **Solanum tuberosum* on the same terrace in April 2003, puzzling because of some anomalies in its flower structure and the apparent absence of tubers; **d)** **Trachyandra divaricata* and **Lobularia maritima* on the terrace at Barrie Crescent in August 1997.

12 *Trachyandra divaricata* (Asphodelaceae; Fig. 8c)

There are no herbarium specimens from the Port Hunter area. The closest documented occurrence is a collection made in 1993 at Birubi Point at the far north-eastern end of Stockton Beach. When I began my observations, *Trachyandra divaricata* was present at North Stockton and Little Park Beach, but not around Macquaries Pier, a situation that did not change over the ensuing years, although it has become more numerous.

Native to South Africa, **Trachyandra divaricata* was collected in 1912 on Coode Island (Heyligers 1999) but, like **Ursinia speciosa*, it did not persist in the area. In the early 1930s **Trachyandra divaricata* became naturalised in the Fremantle area and spread north and south apparently aided by cars and boats (Heyligers 1999a, 2002). In NSW **Trachyandra divaricata* was first reported from Fairy Meadows, north of Wollongong, in 1968. The Wollongong-Shell Harbour area is still the major centre of its occurrence with scattered occurrences in the Sydney region and at Stockton. At most, if not all, of these sites dune restoration has been carried out, often including planting of *Acacia saligna*, a species endemic to Western Australia. Therefore, it seems likely that **Trachyandra divaricata* arrived and has been spread as a contaminant of *Acacia saligna* planting stock.

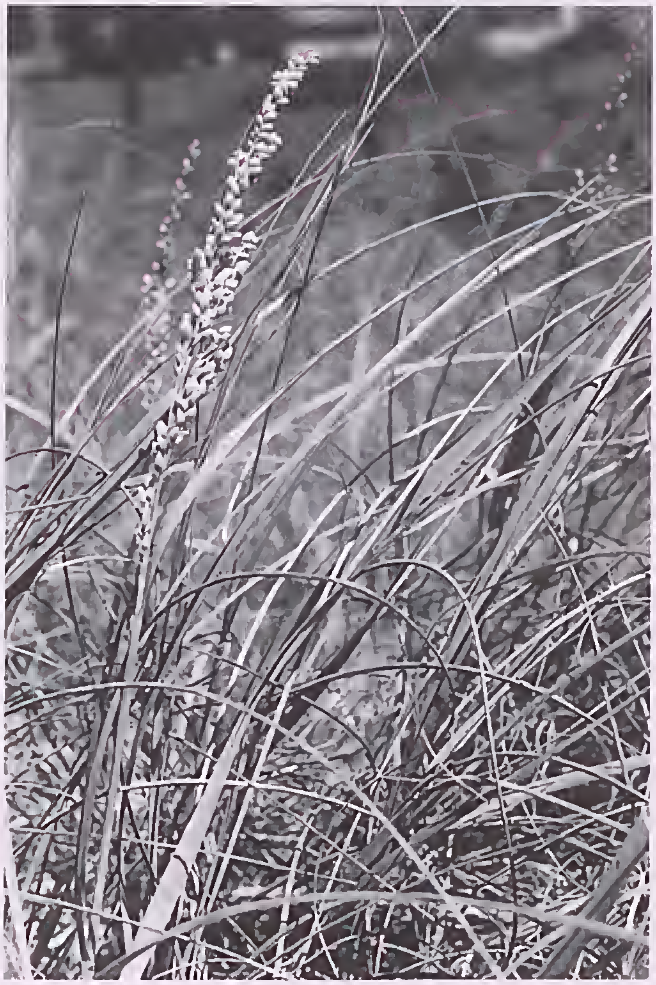

Fig. 9. **Panicum racemosum* in fruit on Eames Avenue terrace in October 2005. Flowering is stimulated by fresh sand accumulating in the sward.

13 *Gladiolus gueinzii* (Iridaceae)

This species, native to south-eastern South Africa, was first collected at Stockton in 1950 and in 1953 at Palm Beach at the entrance to Broken Bay, north of Sydney (Heyligers 1999a). It has since spread along the coast of NSW north as far as South West Rocks, where it was collected in 1964, and to the Eden area in the south where I found it common in 1984. Recently, it has also been collected in Victoria in far East Gippsland close to Cape Howe (Australian Virtual Herbarium information).

14 *Cyperus congestus* (Cyperaceae)

This species, native to South Africa, has spread rapidly on the dune terrace at Eames Avenue. In 1993 it occupied a small area at the entrance to the central path across the terrace, but five years later dominated the groundcover on the street side of the terrace. Rhizome growth has been the main means of dispersal as most flowering stems carry depauperate inflorescences and flowering, during winter and spring, appears to be sporadic. K. L. Wilson (NSW, in lit. 1996) who identified my specimens remarked that 'This is a new record for the North Coast – previously known from New England and from Sydney southwards.'

15 *Panicum racemosum* (Poaceae; Figs. 1 and 9)

This species is native to the Atlantic coast of South America where it is a common, often dominant, foredune plant in the company of **Senecio crassiflorus*, **Hydrocotyle bonariensis* and **Cakile maritima*, among others (Eskuche 1973, Costa *et al.* 1996). On the foredune slope to east of Corroba Park **Panicum racemosum* mingled with *Spinifex sericeus*.

It is not known how **Panicum racemosum* arrived in the Stockton area but it has been present for some time and was regarded by the local population as another kind of marram grass (D. Conway, pers. comm. 1994). However, Mort who in the 1940s surveyed the NSW coast for suitable dune restoration species and was familiar with the Stockton area, does not mention it in his 1949 paper. The other known Australian occurrence of **Panicum racemosum* is near Geelong, Victoria, where it 'has persisted for some years as a troublesome weed around grain storage areas ... but does not appear to have become naturalized elsewhere' (Walsh 1994).

When I began my observations at the Eames Avenue area in 1993 I was puzzled by a 25 m by 7 m patch of a coarse sprawling grass. Being vegetative it defied identification until in December some fertile specimens were obtained, which were keyed out by M. Lazarides as **Panicum racemosum*.

Eight months later the patch at Eames Avenue had expanded to 70 m by 30 m, a clear indication of this species' vigour. Over the following years it became the dominant grass over much of the area, especially in the shoreline section. Flowering only occurs during spring, especially where there has been a fresh supply of sand, and does not appear to produce sufficient seed to explain the rapid expansion. Apparently here, as in its native habitat, it mainly spreads through prolific rhizome growth (Cordazzo and Davy 1999).

Information for authors

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- Artwork supplied should be no larger than A4 (21 cm wide). Any larger images should be brought to the attention of Scientific Editor to see if they need to be outsourced or reduced.
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Tables

- Tables should preferably be portrait rather than landscape shape i.e. taller rather than wider. Column headings should be brief. Each table must be referred to in the text and its approximate position should be indicated. Please remember that tables need to fit into the journal page size.

Fold-up Maps

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